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Strip Mine Drainage

Aquatic Impact Assessment

Interagency Energy/Environment R&D Program Report

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The overall objective of this research program is to demonstrate methodologies for predicting, on the basis of characteristics of the site to be mined, the impact of strip mining on downstream biotic communities. To accomplish this objective and provide data for model verification, sampling programs were initiated at contour- and area-type mining operations. These programs include streamflow and rainfall gaging at both types of mines and surveys of fisheries, periphyton, and macrobenthos surveys at area-mined sites.

Preliminary findings of these field studies indicate that on the Tennessee Cumberland Plateau (1) drainages from mined areas are alkaline rather than acid, and (2) calcium and magnesium concentrations increase as a result of mining in almost every instance. Further, values for iron and sulfate increase in some areas, but not in others, whereas values for trace metals are generally low in all areas.

Several model components have been developed, including a water quality model for nonpoint sources, a continuous streamflow model, and a storm hydrograph model. Other model components being developed or evaluated include additional small-basin water quality models, water quality and quantity routing models, a low-trophic-level stream biota model, and a fisheries resource model.

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by

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FOREWORD

The future reliance on coal as a major energy source in the United States will bring about a substantial increase in mining activity. Because of the greater demand for coal and the stricter environmental regulations governing mining activities, a procedure for predicting the effects of proposed mining on aquatic communities is necessary.

The purpose of this investigation is to develop predictive models for use by regulatory agencies in making planning decisions. The models would be used in the design phase of mine planning to provide regulatory agencies and planners with an easily accessible tool for assessing the impact of policy decisions.

A description of the model components and a discussion of preliminary data collected at area- and contour-mined sites in East Tennessee for model calibration are presented in this report.

ABSTRACT

This research program is aimed to demonstrate methodologies for predicting the impact of strip mining on downstream biotic communities.

To accomplish this objective and provide data for model verification, sampling programs were initiated at contour- and area-type mining operations. These programs include streamflow and rainfall gaging at both types of mines and surveys of fisheries, periphyton, and macrobenthos at area-mined sites.

Preliminary findings of these field studies indicate that (1) drainages from mined areas are alkaline rather than acid, and (2) calcium and magnesium concentrations increase as a result of mining in almost every instance. Furthermore, values for iron and sulfate increase in some areas, but not in others, whereas values for trace metals are generally low in all areas. The predominant fish in small Cumberland Plateau streams is the creek chub (Semotilus atromaculatus), and its primary food source is aquatic invertebrates, including midge larvae, springtails, and aquatic mites.

Several model components have been developed, including a water quality model for nonpoint sources, a continuous streamflow model, and a storm hydrograph model. Other model components being developed or evaluated include additional small-basin water quality models, water quality and quantity routing models, a low-trophic-level stream biota model, and a fisheries resource model.

This report was submitted by the Tennessee Valley Authority, Office of Natural Resources, in partial fulfillment of Energy Accomplishment Plan 80 BDS under terms of Interagency Agreement EPA-IAG-D8-E721 with the U.S. Environmental Protection Agency. Work was completed as of December 31, 1977.

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SECTION 1

EXECUTIVE SUMMARY

As demands for domestic energy increase and use of coal becomes even more dominant as a part of U.S. energy policy, a procedure for predicting the effects of proposed mining on the aquatic resource will be needed. Development of such procedures is the objective of this investigation.

Field studies were initiated at nine small watersheds within the Cumberland Plateau region of east-central Tennessee. Data from these studies will be used for model development and verification. A few generalizations can be drawn from these studies:

1. Acid mine drainage is the exception rather than the rule within the Tennessee Cumberland Plateau. None of the mined watersheds had acid drainages. In fact, pH values were somewhat higher (by 0.5 to 1.0 unit) in mined watersheds than in unmined watersheds nearby.

2. Alkalinity, calcium, and magnesium values were higher in mined areas than in unmined areas. Leaching of these materials from previously unweathered strata is the most plausible explanation for an increase in pH at mined stations.

3. Values for sulfate and iron--an indication of acid information--increase dramatically at some sites, but only slightly at others, indicating that acid formation and subsequent neutralization are occurring in some areas, whereas little or no formation is evident in others.

4. Trace metal concentrations were generally low when compared with values encountered in many other mining situations. Concentrations did increase, however, at those areas in which acid production was occurring.

5. Manganese concentrations increased with mining at all stations.

6. The most serious water quality problem encountered was erosion and subsequent sedimentation.

7. Analysis of soil cores from the Fentress County sites indicated that acid conditions will not predominate in drainage. This conclusion is substantiated by the alkaline drainages and illustrates that overburden analysis can predict acid-alkaline conditions before mining.

8. Natural streams in the area appeared to be dominated by the creek chub (Semotilus atromaculatus), with smaller populations of the fathead minnow (Pinephales promelas) and the blacknose dace (Rhinichthys atratulus). Mining decreased both the diversity and number of fish within the affected streams.

9. The primary fish food organisms, in decreasing order of importance, are midge larvae (Chironomidae), springtails (Collembola), and aquatic mites (Arachnida).

Model development has progressed concurrently with the field studies. Much of the work has involved modification of existing models to account for strip mine effects. Most of the modification has involved application of the models to sites in southern Appalachia so that predicted values can be compared with actual data, and model algorithms and coefficients can be adjusted. Five tasks have been accomplished to date:

1. A water quality model for nonpoint sources under unmined conditions that is based on hydrology and geology of the watershed has been verified. Although quite simple, the model predicts natural stream water quality so that changes to the water quality as a result of mining may be assessed.

2. A continuous streamflow model, RUNOFF, which can be used interactively, has been developed to predict instantaneous flows when watershed characteristics and rainfall are known. The model is now being modified after a largely successful verification run using project data.

3. A stream temperature model has been applied to four sites within the Cumberland Plateau and verified.

4. A suspended solids model has been coupled with RUNOFF to predict instantaneous solids concentrations. The model is a modification of the Universal Soil Loss Equation. Verification has been partly successful, but the model is being modified further.

5. A stream morphology model for use in routing flow and water quality downstream has been developed and verified so that top width, area, velocity, and depth can be simulated if stream drainage area and slope are known.

SECTION 2

INTRODUCTION

The environmental problems associated with mining coal are widespread, serious, and often obvious. Much of the obvious degradation is associated with old orphan mines that were left unreclaimed or poorly reclaimed. In the last ten years, surface mining regulations have been enacted in all the eastern coal-producing states which, along with more stringent Environmental Protection Agency (EPA) regulations and Federal laws, will ameliorate many of these problems. Coal mining will continue to impact the environment, because any disturbance of the earth's surface will alter the environment to some degree. Also, because of the increased emphasis on coal in the Nation's energy program, there is still a potential for environmental degradation, despite more stringent legislation, as a result of aggregated effects.

Objective assessment of the environmental impact of coal mining is not simple. Most research done in the past has been directed toward a study of the effects of past mining operations on water quality. Such studies do not lead to methods for transferring the results to other locations, for which the physical or geochemical conditions differ or the mining or reclamation techniques vary. Those few studies that have involved the modeling of mining effects usually required copious amounts of data for model application, which severely limits their use. Also, past studies have focused on only a few conventional water quality parameters.

A problem arises from any generalized attempt to assess the environmental impacts of coal mining: How does one equate the differences in reported effects with variations in site characteristics and in mining and reclamation techniques? In essence, no methodology exists for predicting cause-and-effect relationships. The topographic characteristics of a site to be mined and the chemical-physical characteristics of the coal, overlying rock, and soil can cause considerable variation in the effects of mining on the aquatic resource. These effects can be substantially modified by mining techniques, such as soil disposal and contour vs. area, and by reclamation techniques, such as erosion and sedimentation controls and revegetation alternatives. The effect on scale must also be considered when evaluating the impact of mining on the aquatic environment. Even with reclamation measures aimed at minimizing the release of sediment and acidity, the quantity and quality of streamflow will change. Both the local streamflow regime and the water quality immediately below any mine will be altered. Because downstream effects diminish as a result of dilution from other areas, the impact of a single mine with adequate reclamation of the aquatic environment tends to be localized, often with the primary impact confined to a small stream. However, when mining becomes extensive in a watershed, these effects can accumulate and impact the biological productivity and usefulness of larger streams. No techniques are available for assessing the cumulative effects on larger streams of mining extensive areas under even controlled reclamation strategies.

Mathematical models offer the best methodology for quantitatively assessing environmental consequences that result from several factors operating simultaneously. These models must consider the (1) physical and geological characteristics of the mining site, (2) mining techniques used, (3) reclamation techniques used, and (4) hydrology of the area. The models must also be able to integrate the effects of multiple mining sites at some point downstream from these operations. Finally, changes in water quality and quantity must be translated into biological and aesthetic impacts and, where possible, assigned costs. This applied research project is designed to provide a composite model that can be used when planning the development of surface mines. The model allows investigations of the potential effect of various mining reclamation techniques (manipulative) or the (1) quality and quantity of local streams and (2) indigenous aquatic biota. It also allows for prediction of cumulative effects of pollutants from multiple mines with various "background" or control scenarios.

The models are being designed for use by regulatory agencies in making planning decisions. The models can be used to (1) investigate the suitability of a site to be mined on the basis of geology and coal chemistry involved, (2) evaluate the adequacy of reclamation measures being proposed by a miner, (3) investigate the cumulative impacts of multisite mining in a large watershed, or (4) assess the consequences to the aquatic ecosystem that would result from changes in reclamation regulations or in effluent limitation standards.

As a part of model development, information must be obtained not only on the chemical and physical characteristics of mine drainage but also on the effect of that drainage on the aquatic community. Several types of information are necessary for evaluation:

1. Mining data, such as type of mining, total area disturbed, approximate schedule of operations, number and type of sediment control structures, depth of coal seam, length of contour cut, and distance of the cut from the receiving stream.

2. Reclamation data, including the schedule for reclamation, fertilization and liming rates, approximate slopes of reclaimed areas, type of revegetation used, and success of revegetation efforts.

3. Climatological information, such as hourly rainfall, storm intensity and duration, and temperature.

4. Land cover, including land use, riparian land cover, and road systems.

5. Watershed characteristics, such as topography, soils information, drainage areas, any point sources of pollutants, and drainage networks.

6. Overburden characteristics, including trace metal content and the amount and strength of acid-forming and neutralization materials.

7. Stream-associated characteristics, including channel slope, pool-to-riffle ratios, morphology vs. discharge relationships, bed grain size, and dispersion coefficients.

8. Water quality, including both physical (pH, temperature, etc.) and chemical (acidity, nutrients, minerals, and trace metals) data.

9. Aquatic community characteristics, qualitative and quantitative, of periphyton, benthos, and fish.

This type of information is essential to an understanding of cause-and-effect relationships. Such data, however, are also needed for model development; but in applications, the model will require only descriptive information of the site.

The national goal of energy independence dictates that coal extraction will increase significantly in the near future, and because of the far-reaching effects that are involved, policy decisions are becoming more critical. Because conservation of natural resources is an agency objective, the decision to construct a fossil-fueled generating plant should include assessment of any potential mining costs to the environment and, consequently, to the social well-being of the people. Likewise, a decision to enforce effluent limitations or stringent reclamation standards by a regulatory agency should be based on the determination that the environmental and social benefits to be derived are commensurate with the economic costs involved. This kind of policy decision will necessitate the use of models such as those being developed in this project.

MODEL DESIGN CONSIDERATIONS

The model under development is being designed for easy use in providing cause-and-effect relationships for planning applications. These goals dictate several approaches that are incorporated into this model.

Nonpoint Source Models

Nonpoint source models for application at ungaged, unmeasured locations will be developed. If the models are to be applied easily, lengthy data-gathering to calibrate these models cannot be justified. Instead, deterministic components must be used to the extent possible, with regionalization of nondeterministic components. A deterministic model component is one that defines the process so well that, when it is applied, only site characteristics need be measured. When processes are very complex, simplified models must often be used that imitate process behavior. Typically, these models must be adjusted to data by using optimization techniques to determine model parameters. If the parameters determined by adjusting the model to many sets of data at different locations are related to site characteristics in a second step, the model is said to be regionalized, because the model parameters can be predicted from the characteristics of ungaged sites (at least in the general region in which the model was calibrated). By using this

approach, data from many other locations on the Cumberland Plateau can be used, thus minimizing the need for costly project data. In either case, however, the result is a nonpoint source model component that can be applied at any location on the basis of only the site characteristics.

First-Generation Model

First-generation model components are used to the extent possible to simplify model applications. First-generation models were defined by Betson (1975) as those that can be calibrated and used with published data. Thus, application of first-generation, deterministic model components would require only mapped data; calibration of a first-generation, regionalized model would require only published data, and subsequent application would require only mapped data. In other words, an objective in developing this model is to minimize the need for gathering expensive field information to apply the models. Although not an explicit goal of this study, these models are being designed for use in an interactive computer mode, provided suitable spatial land cover, soil, geology, topography, and other information are stored on the computer. This latter objective also requires minimization of the field data requirements for the model. (It also will necessitate interfacing these models with models developed at other projects.)

Compartmentalization of the Model

The model will be compartmentalized to simplify modifications and improvement. If first-generation models are to be used, then simplified approaches will have to be taken because, as the complexity of a model increases, the input information and data requirements generally increase. A first-generation model is often adequate for planning applications for which a model requiring much input information could not be economically justified. However, if the model is compartmentalized, the model components can be improved as necessary or when improved formulations are developed. Thus, a model structure that can be adapted for other purposes will be provided.

Linking of Mining and Stream Ecology

The model will link mining and stream ecology to allow investigation of cause-and-effect relationships with a single model. Because changes in water quality have impact only when they affect living organisms (man included), a surface mine model must include provisions for considering effects on aquatic biota. The component model compartment will be interfaced in such a manner that, beginning with the mining and reclamation, the effects will cascade through model components until the impact on the biotic component is considered. Thus, rather than predicting only physiochemical effects, a capability for evaluation based on the effects on the entire ecosystem will be provided.

Background Model Simulation Capability

A background model simulation capability will be provided. Any impacts to streamflow quality or quantity or to the aquatic biota that may result from mining must be quantified in relation to the background or natural stream conditions. Impact assessment involves evaluating the effects of changes that occur. Therefore, to measure change (impact), the models must also be capable of predicting background conditions.

SECTION 3

STUDY WATERSHEDS

Two study sites are located on the Cumberland Plateau area of eastern Tennessee. Topography of the plateau varies from gently rolling hills in the northwest to rugged mountains in the northeast. The stratigraphy is Pennsylvanian in origin and is characterized by sandstones and shales, with intermittent beds of coal. Overall, the sequence can be divided into two principal components--an upper part, containing thick beds of shale with thin, discontinuous sandstones; and a lower section, consisting largely of thick conglomerates and sandstones, separated by equal amounts of shale. In general, the upper sequence is preserved only in the Cumberland Mountains, whereas the lower sandy sequence caps the remaining flat-topped portion of the plateau (Johnson 1972).

The northern part of the plateau is drained by the Big South Fork Cumberland River. The New River, North White Oak Creek, and Clear Fork River are primary tributaries to the Big South Fork Cumberland River.

AREA-MINED SITES

The study sites chosen to reflect area-mined conditions are located in Fentress County near Jamestown, Tennessee (Figure 1). The stratigraphy reflects the lower sandy sequence of Pennsylvanian lithology found on the plateau. Strata in the mined area consists of sandstone members of the Rockcastle conglomerate overlying the Nemo coal seam. The mined area is drained by Crooked Creek, a primary tributary to the Clear Fork River.

Four water quality and three biological sampling stations are located on Crooked Creek and its tributaries. Two water quality and biological sampling stations are also located on streams draining unmined areas. Rainfall and streamflow gages located at two mined sites and one unmined site on Crooked Creek were installed early in July 1976.

Lynn Branch (Station LY 0.8)

Lynn Branch is a first-order stream (i.e., it has no tributaries) located about 6.4 km ESE of Jamestown, Tennessee. The stream is a tributary of Mill Creek, which drains into North White Oak Creek. The drainage area is about 103 hectares (ha) at the sampling station, which is located at river mile 0.8. The creek, 0.6 to 2.0 m wide, has sand, gravel, and bedrock substrate, and its depth varies from 2 cm to 0.2 m. Stream canopy is greater than 90 percent throughout the forested portion (89 percent) of the watershed. Lynn Branch served as one of three control stations.

Long Branch (Station LB 4.6)

A second control station is located on Long Branch about 2.5 km E of U.S. 127 at Grimsley. Long Branch is a first-order tributary of South Prong Clear Fork Creek, which joins Crooked Creek to form the

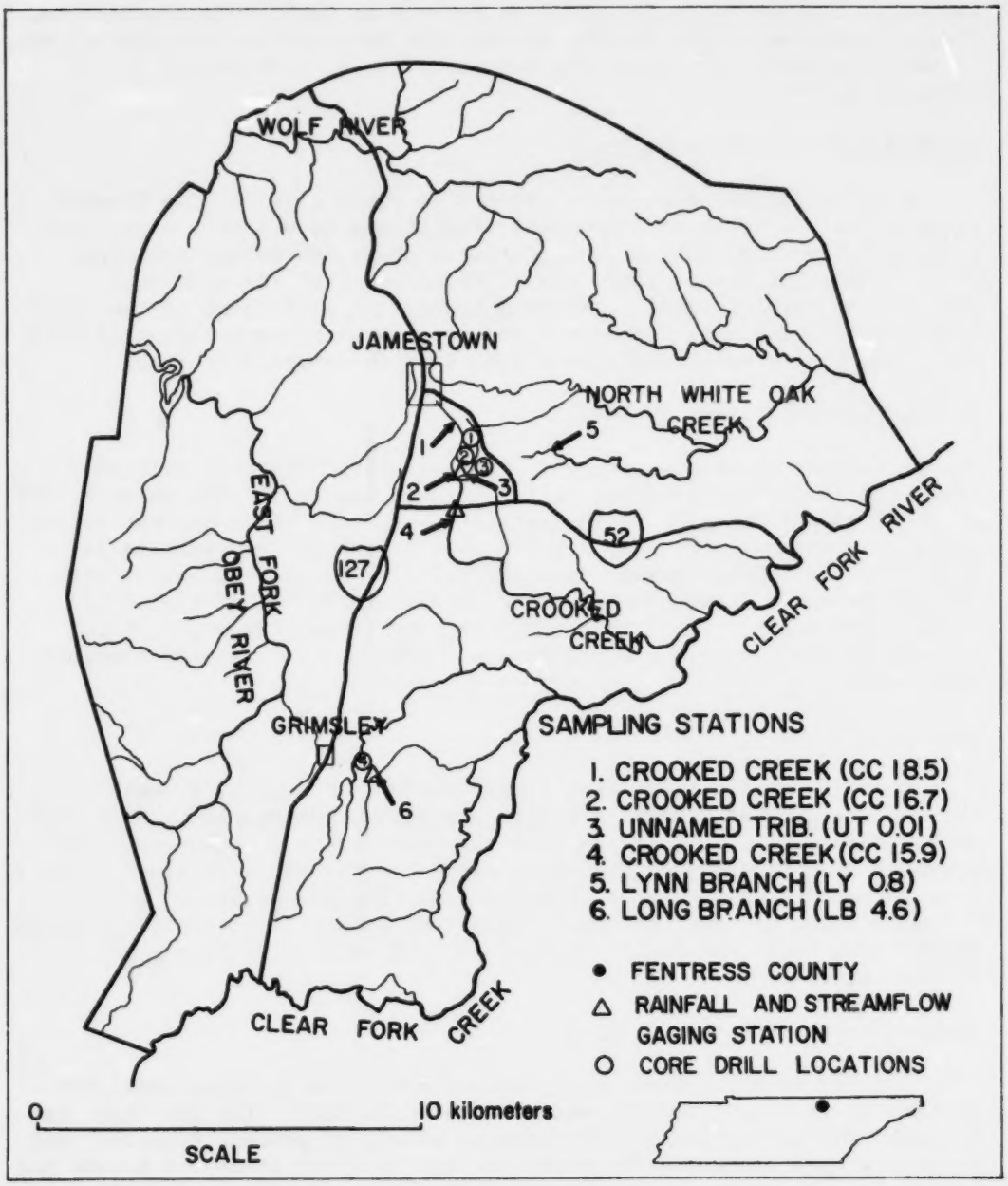

Figure 1. Sampling stations--Fentress County.

Clear Fork River. The drainage area is about 290 ha at the stream gage and sampling station, which are located at river mile 4.6. The stream is 0.9 to 2.1 m wide and 2.5 to 0.9 m deep at this point. The substrate varies from areas of small gravel to bedrock to deep, decaying detritus. Stream canopy was about 90 percent over the forested portion (89 percent) of the watershed. The remainder was pastureland, with forest canopy of about 80 percent.

Crooked Creek (Station CC 18.5)

A third control station is located at river mile 18.5 on Crooked Creek about 2.4 km SE of Jamestown. The stream is 0.3 to 1 m wide and 0.15 to 0.6 m deep. The drainage area is about 180 ha and contains about 31 percent forest land. Most (69 percent) of the watershed is pastureland, with several small farm houses. A small part of the watershed drains Jamestown, Tennessee, and represents urban-residential land use. The bottom substrate ranges from sand to decaying detritus.

Crooked Creek (Station CC 16.7)

A second station on Crooked Creek is located at river mile 16.7 about 2.9 km downstream from station CC 18.5 and represents an area that is about 13 percent mined. The remaining land use is 31 percent forest and 56 percent pastureland. Total drainage area at this station is about 725 ha. The substrate is small gravel, bedrock, and sand, with the percentage of sand cover increasing as a result of erosion from strip-mined areas. The area sampled is rather homogeneous, 0.15 to 0.6 m deep and 3 to 4.5 m wide, with an undercut bank on both sides of the creek.

Unnamed Tributary (Station UT 0.01)

About 50 m downstream from sampling station CC 16.7, a small tributary enters Crooked Creek. A sampling station, designated UT 0.01, was established 0.01 mile upstream from the mouth of this tributary. The drainage area is about 65 ha, about 43 percent of which is mined, 5 percent forested, and 52 percent pastureland. The stream is 2.5 cm to 0.3 m deep and 0.3 to 1 m wide. The bottom substrate alternates between bedrock and sand. Rainfall, streamflow, and water quality are measured at this site.

Crooked Creek (Station CC 15.9)

A final sampling station is located about 1.3 km downstream from station CC 16.7 on Crooked Creek at river mile 15.9. The drainage area is about 950 ha, 13 percent of which is mined, 32 percent forested, and 55 percent pastureland. The creek in this locality is 1 to 6 m wide and 0.15 to 1 m deep; the substrate is mostly sand and silt, and a 200-yard riffle exists below the Allardt Highway bridge. Above the highway bridge are the remains of a silt dam, which was breached during the winter of 1975. Since this occurred, the turbidity has increased markedly at this station. The stream canopy is about 60 percent in the vicinity of the sampling station. Rainfall, streamflow, water quality, and biota were measured at this site.

The study watersheds were first mined during the summer of 1975. Mining was completed above station UT 0.01 about April 1976 and above stations CC 16.7 and CC 15.9 during September 1976. Mining was conducted using the standard open-pit method. Reclamation techniques included topsoil segregation, return to approximate contour, mulching, liming, and seeding. Several sediment traps and diversion ditches were installed during active mining. Additional sediment control measures were instituted after mining ceased. Sediment traps, generally of poor design, consisted mostly of wooden barricades built across the stream channel proper, which appears to be prevailing practice throughout much of Tennessee. Because monthly water quality samples began in February 1976 at all six stations, no background information was collected in the study watersheds.

CONTOUR-MINED SITES

Most of the contour mining in the State of Tennessee occurs in the New River Basin in east-central Tennessee. The basin, about 989 km^2 in area, is located above a U.S. Geological Survey (USGS) stream gage at New River and is contained wholly in Anderson, Campbell, Morgan, and Scott Counties. The basin has been well mapped, including detailed delineation of mined and unmined regions (Hollyday and Saver 1976).

The stratigraphy reflects the upper, shale-dominated sequences of Cumberland lithology. The mined areas drain large vertical sections of this lithology. The principal drainages are Smokey Creek, Brimstone Creek, Paint Rock Creek, Buffalo Creek, Beech Fork, and Ligias Fork.

The intensity of the mining effort within the basin has moved many groups interested in mining to develop various research or monitoring programs. An interagency committee was established to eliminate duplication of efforts and interfacing agency programs, thus extending the usefulness of the data. This group contains representatives from TVA; USGS; the U.S. Army Corps of Engineers; the U.S. Department of Agriculture, Soil Conservation Service; Oak Ridge National Laboratory; the University of Tennessee; and the Tennessee State Planning Office, Tennessee Division of Surface Mining, Tennessee Department of Conservation, and Tennessee Wildlife Resources Agency.

The USGS operates all hydrological gaging stations in the basin. TVA and all other agencies obtain rainfall and streamflow records through the USGS, which also conducts a larger-scale program aimed at evaluating the hydrological impact of mining in southern Appalachia. Of primary interest are those studies dealing with storm-event sampling of sequential downstream stations and sediment movement and storage.

The U.S. Army Corps of Engineers was directed by Public Law 93-251, which created the Big South Fork National River and Recreation Area, to formulate a comprehensive plan for the New River Basin for "programs to enhance the environment and conserve and develop natural resources, and to minimize siltation and acid mine drainage." The Corps retained a consultant, L. Robert Kimball (1976), to assist in carrying out this task. Kimball developed a 12-point program that includes an extensive field reconnaissance survey, in which 300 water quality grab samples

were collected to identify intensive sources of pollution. This part of the program was completed, and a secondary phase of sampling was begun, whereby a monthly grab sample is collected at 61 locations identified during the reconnaissance survey. TVA will receive these data and has made recommendations for trace metal analyses at several sites.

Most of the data produced for use in this project are collected as part of a cooperative agreement with the University of Tennessee, whose program is largely funded through the Tennessee State Department of Public Health. TVA has agreed to fund rainfall and streamflow gaging at three watersheds in the basin; in return, the University of Tennessee has agreed to furnish TVA with their project data, which includes investigations of (1) the hydrological modifications resulting from watershed disturbance by mining; (2) contaminant flows from mining spoil and their dependence on spoil bank hydrology and mineralogy; (3) the behavior of potentially toxic heavy metals in the streambed and suspended sediment ultimately carried out of the basin; and (4) biological differences as related to observational differences between mined and unmined basin streams, heavy metal accumulations in stream biota, and ATPase ion pump system in resident biota as an indicator of sublethal stresses on organisms in disturbed watershed streams.

Those studies of greatest potential use to TVA include parts of tasks 1, 2, and 3. Most of this work is carried out in six small watersheds within the basin (Figure 2), three of which represent contour-mining operations and prevailing practice of reclamation; two areas represent unmined conditions. Mining has recently begun on a third basin that was originally selected to represent unmined conditions.

Topography of all watersheds is similar, with average slopes ranging from 31.9 to 38.4 percent. Stream channels are nearly as precipitous, with average channel slopes ranging from 7.4 to 8.4 percent for the larger Indian Fork and Bowling Branch watersheds to 26 percent for Bills Branch, the smallest watershed. Channels draining unmined areas consist of alternating rapids with larger boulders to bedrock "waterslides" to cobbles. Channels of mined watersheds exhibit sediment accumulations in eddy areas, with heavy deposits at the mouth.

Lowe Branch and Bowling Branch

The two unmined basins, Lowe Branch and Bowling Branch, represent drainage areas of about 240 and 760 ha, respectively. Lowe Branch is located about 1.6 km S of Norma, Tennessee, and is tributary to the New River. Bowling Branch is located 316 km SW of Smokey Junction and is tributary to Smokey Creek. The watersheds are almost completely forested, with limited logging operations in the Bowling Branch watershed. Lithology of these watersheds ranges from the lower Red Oak Mountain formation to the slatestone formation; these sequences are characterized by clayey to sandy shales, light brown to dark gray in color with intercalated siltstone and sandstone, and localized thin coal seams. The only coal reserve of note is the Big Mary coal, 40 to 120 cm thick, which appears at an elevation of about 2200 ft in both basins (Luther 1970).

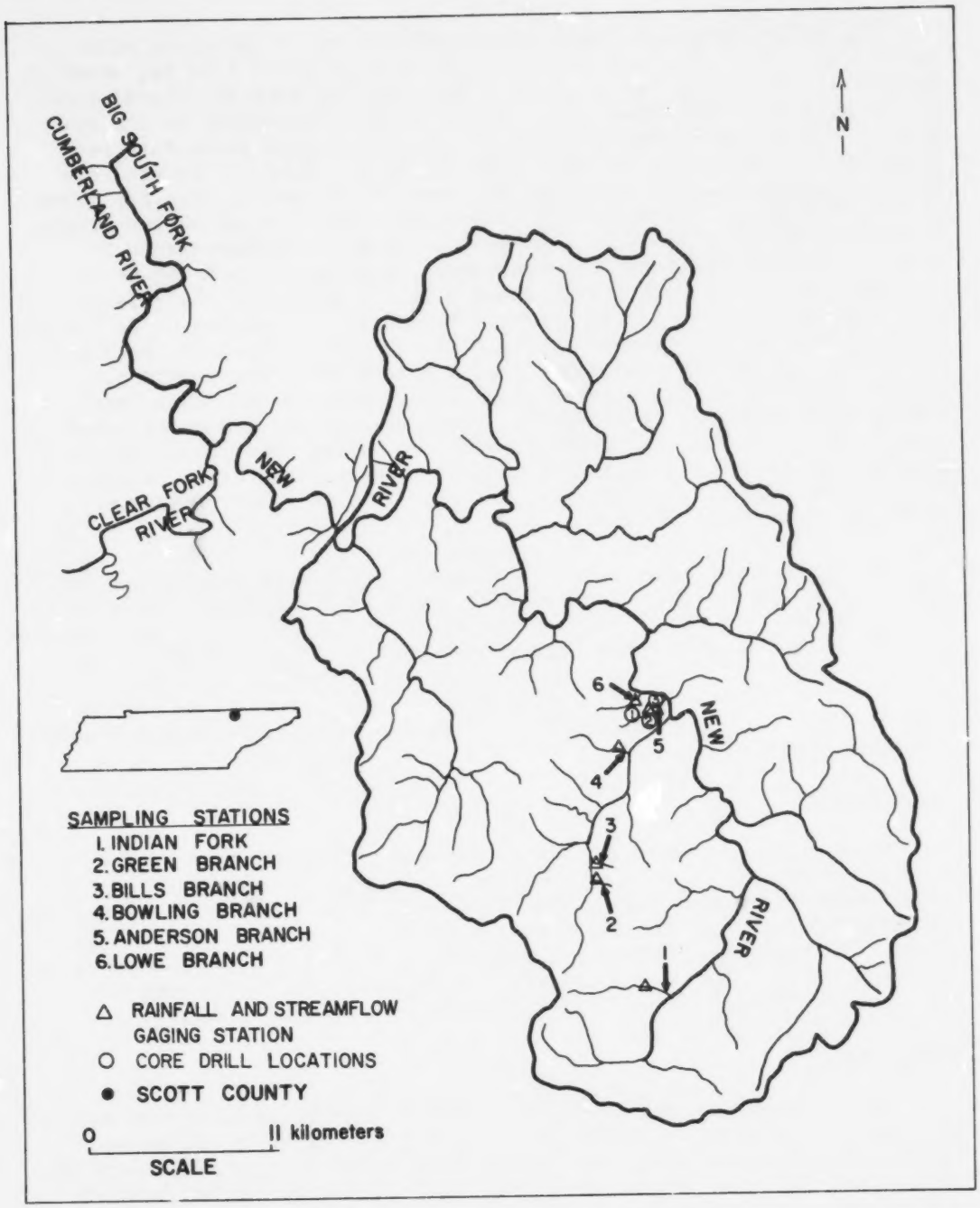

Figure 2. Sampling stations--New River watershed.

Indian Fork

The Indian Fork watershed represents an area of extensive mine operations. The watershed represents an area of about 1119 ha, about 19 percent of which (210 ha) is mined. The sampling site is located about 0.5 km W of Braytown, Tennessee. Indian Fork is tributary to the New River. The Big Mary, Walnut Mountain, and Pewee coal seams have been mined on a larger scale for more than 20 years. Most of the coal has been extracted by surface mining, but some underground mining has taken place. The Big Mary seam (about 2250-ft elevation) is of marine origin, as evidenced by a 7.6- to 10.1-cm zone of mudstone characterized by marine fossils. The remaining overburden is primarily a homogeneous mudstone, medium to dark gray. About 6 to 9 m above the coal, large disc-shaped carbonate masses appear. These masses, ranging up to 1.2 m in diameter, are distributed sporadically. About 21 m above the Big Mary coal, the gray marine shale grades upward into interbedded siltstones, sandstones, and shales. The Walnut Mountain and Pewee coals (about 2650- and 2600-ft elevation, respectively) are generally mined simultaneously. The overburden consists of shales, sandstones, siltstones, and siderite nodules and beds. A carbonaceous layer, similar to but thicker than that found above the Big Mary, is found immediately above the Pewee coal (Garman 1975).

Reclamation of mined areas is varied. Strip mine regulations for the State of Tennessee are reviewed in Appendix A. Because little or no effort was made to stabilize mine spoils in the basin before the Tennessee Strip Mine Law of 1967, many orphan mines exist. Also, mining of the Big Mary seam was virtually completed before March 1972, when specific regulation criteria were enacted in the form of amendments to the 1967 law. Active mining in the basin is limited mainly to the Walnut Mountain and Pewee seams.

Bills Branch

Bills Branch, a second mined watershed, is tributary to Smokey Creek, a primary tributary of the New River. The watershed is located about 10 km SW of Smokey Junction, Tennessee. The Bills Branch watershed represents an area of about 170 ha, of which 9.8 percent (16.7 ha) is mined. Mining began in this watershed in late 1974 and was completed in September 1975. The seam mined was the Big Mary coal. The area was reclaimed according to the Tennessee Surface Mining Law of 1972.

Green Branch

The Green Branch watershed is separated from Bills Branch by an extension of Bear Knob. Green Branch is also a tributary of Smokey Creek. The drainage area, 357 ha, is about twice that of Bills Branch; 24 percent of the watershed is mined. Most of the mining has been in the Big Mary and Pewee seams, but some has involved the Grassy Springs and Jellico coals. Mining was initiated in the basin during 1972 and completed in late 1975. About 60 percent of the reclamation was carried out under 1972 regulations, and the rest complied with the 1974 law.

Anderson Branch

The remaining small watershed, Anderson Branch, was originally chosen as a control site; however, mining of the Jellico seam began in the spring of 1976 and will be completed during March 1977. The watershed divide is being used as a haul road for mining beyond the watershed. Total disturbance is estimated to be 15.8 ha, or 7.5 percent of the 210-ha drainage area. The Jellico coal adjoins the base of the Indian Bluff formation. The major strata are shale, sandstones, and siltstones, the most persistent and thickest sandstone member overlying the Jellico coal. Anderson Branch, tributary to the New River, is located about 2.5 km S of Norma, Tennessee.

SECTION 4

MATERIALS AND METHODS

AREA-MINED SITES

Samples were analyzed for a wide variety of physical and chemical properties (Table 1). Some experimentation necessary for developing optimum analysis of dissolved, suspended, and total metals is reflected in the inconsistency of early metals analyses. Analysis for pH, acidity, and alkalinity and filtrations for dissolved metals were carried out in the field whenever possible. However, in some instances samples had to be transported to the laboratory. In these cases, the samples were iced and transported immediately, and the analyses were carried out within 4 h of sample collection. Rainfall and streamflow gaging stations were installed at stations UT 0.01, LB 4.6, and CC 15.9 during 1976. Automatic water samplers were purchased and placed onsite at stations UT 0.01 and CC 15.9 during the same year.

TABLE 1. WATER QUALITY ANALYSES--FENTRESS COUNTY SITES

Field parameters	Total minerals	Nutrients
pH	Solids	Total phosphate
Alkalinity (total)	Hardness	Orthophosphate
Acidity	Cl^-	Total organic carbon
Flow	$SO_4^=$	Total inorganic carbon
Temperature	F^-	Nitrite and nitrate nitrogen
Specific conductivity	Na^+	Total Kjeldahl nitrogen
	Turbidity	

Dissolved minerals	Metals (total, suspended, dissolved)			
SiO_2	Al	Cr	Hg	Ni
	As	Cu	K[a]	Pb
	Ca[a]	Dc	Mg	Se
	Co	Fe	Mn[a]	Zn

[a]Total metals analyses only.

Five stations (CC 16.7, CC 18.5, CC 15.9, LB 4.6, and LY 0.8) were sampled monthly to determine the structure of lower-trophic-level biotic communities. Qualitative and quantitative analyses of the zoomacrobenthos and periphyton were performed. Additional water quality samples were collected and analyzed for pH, temperature, dissolved oxygen, hardness, alkalinity, acidity, and sulfate concurrently with collection of biological samples.

Four stations (CC 16.7, CC 15.9, LY 0.8, and LB 4.7) were sampled monthly to determine fisheries populations. Fish sampling involved the use of a Smith-Rout, 325-V, pulsating, DC, backpack shocker and a block net at the head and lower end of the area to be shocked, which was 30 m long.

CONTOUR-MINED SITES

The University of Tennessee began a sampling program in the basin in January 1975. Water quality samples are collected weekly and analyzed for many parameters: pH, sulfates, alkalinity, suspended solids, turbidity, chlorides, total solids, and total and dissolved metals (aluminum, calcium, cadmium, cobalt, chromium, copper, iron, magnesium, manganese, nickel, lead, tin, and zinc). All analyses were performed by standard methods (EPA 1974).

Continuous hydrological gaging of rainfall and streamflow was begun at the onset of the study on Indian Fork, Bills Branch, and Lowe Branch. Anderson Branch and Bowling Branch were provided with sharp-crested weirs and staff gages for instantaneous measurements. By mid-December 1974, all six basins were equipped with continuous rainfall and streamflow gaging equipment.

SUMMARY

Sampling stations were established at mined and unmined basins in two geologically dissimilar areas of the Cumberland Plateau. Mining and land use information is summarized in Table 2.

TABLE 2. SUMMARY OF SITE INFORMATION

Sampling station	Area (ha)	Percent mined	Seam	Dates of mining	Percent forest	Percent rural-resident
			Fentress County			
Lynn Branch (LY 0.8)	103	0	-	-	89	11
Long Branch (LB 4.6)	280	0	-	-	89	11
Crooked Creek (CC 18.5)	180	0	-	-	31	69
Crooked Creek (CC 16.7)	725	13	Nemo	4/75 - 9/76	31	56
Unnamed Tributary (UT 0.01)	52	43	Nemo	9/75 - 9/76	5	52
Crooked Creek (CC 15.9)	950	13	Nemo	4/75 - 9/76	32	55
			New River Basin			
Bowling Branch	764	0	-	-	100	0
Lowe Branch	238	0	-	-	100	0
Anderson Branch	210	7.5	Jellico	3/76 - 3/77	92	0
Indian Fork	1119		Big Mary	Late 50's - 72		
		18.9	Walnut Mountain	/ 52 - Present	81	0
			Pewee	/ 52 - Present		
Green Branch	357	1.7	Jellico	72 - 73	76	0
		12.8	Big Mary	73 - 12/74		
		7.4	Pewee	6/75 - 9/75		
		2.2	Grassy Springs	6/75 - 9/75		
Bills Branch	174	9.0	Big Mary	12/74 - 9/75	90	0

SECTION 5

PROJECT STUDIES

Preliminary findings from data collection activities are compared for the Fentress County (area-mined) and New River Basin (contour-mined) sites. Hydrological results are presented in the form of model tests using data developed from similar studies. Test results for several models are also presented.

WATER QUALITY

Water quality data for the six Fentress County sampling sites are divided into three groups to facilitate presentation and interpretation of the data from the standpoint of land use. Group M consists of the three mined sites, CC 16.7, UT 0.01, and CC 15.9. Group F consists of the two basins, LY 0.08 and LB 4.6, within which silviculture represents the prime land use. Group A consists of data collected at station CC 18.5, the only unmined basin with significant agricultural activity. These data are presented in Figures 4 through 9 as monthly averages; simple statistics from individual stations are presented in Tables 3 and 4.

pH-Acidity-Alkalinity

Although the term "mine drainage" typically connotes acid conditions, more alkaline ($pH \geq 6.0$) conditions usually exist in the mine drainages in the Cumberland Mountain area of Tennessee. As part of the U.S. Army Corps of Engineers' reconnaissance survey of the New River Basin, 319 grab samples were collected throughout the basin. Of these samples, only 28 (9 percent) exhibited a pH of 6.0 or below; only 40 (13 percent) contained zero or negative net alkalinity. Data indicate that mining increases pH and alkalinity. Figure 3 shows that, at the Fentress County (contour-mined) sites, alkalinity is highest in agricultural drainage, lower in mined drainage, and lowest in streams draining forested areas. This reflects the extremely low buffering capacity encountered in plateau streams.

Figure 4 indicates that pH is lowest in forested drainage and slightly elevated in both mined and agricultural drainage, with no appreciable difference existing between the two. Lower pH's in the streams draining forested areas result primarily from dissolution of atmospheric CO_2 into the unbuffered waters and from organic acids from decaying vegetation. Increased pH's and alkalinity in the streams draining mined and agricultural areas result primarily from dissolution of substances from newly exposed and previously unweathered strata.

Acidity values (Figure 5) exhibit no consistent differences for the three groups. These data indicate that mining increases both pH and alkalinity, with little effect on acidity. They also suggest, however, that similar effects are encountered for agricultural areas. Increases in alkalinity and pH after mining have been documented by Connell (1976), Curtis (1972), and Plass (1976). Acidity and pH appear to be time-independent, except for a possible increase in pH in Group F during late

TABLE 3. MEANS AND RANGES OF PROJECT DATA FROM FENTRESS COUNTY SITES

Location	Statistic	Constituent (mg/L)						
		pH	SO_4	Total suspended solids	Total hardness (as $CaCO_3$)	Alkalinity (as $CaCO_3$)	Acidity (as $CaCO_3$)	Total iron
Lynn Branch, (LY 0.8), unmined	Mean	6.23	2	7	9	4.11	10	0.58
	Range	5.35-6.70	1-5	1-39	7-12	1-8	1-37	0.23-1.2
	N	16	12	7	11	16	16	7
Long Branch (LB 4.6), unmined	Mean	5.60	5	11	11	5.43	12	1.7
	Range	5.0-6.70	2-14	1-33	5-25	0.5-18	2-33	0.14-3.9
	N	16	9	7	10	16	15	7
Crooked Creek (CC 18.5), unmined	Mean	6.76	8	26	37	24.59	8	1.8
	Range	6.10-7.60	2-16	11-50	23-54	14-44	4-14	0.93-2.7
	N	11	7	5	10	11	11	6
Crooked Creek (CC 16.7), mined 13%	Mean	6.82	7	54	35	19.3	10	4.0
	Range	6.20-7.60	3-14	2-300	23-46	13-29	1-42	1.0-16
	N	16	12	7	10	16	16	7
Crooked Creek (CC 15.9), mined 13%	Mean	6.88	18	77	43	16.60	8	2.5
	Range	5.80-7.10	9-56	4.0-400	24-80	3.2-27	1-18	1.1-3.6
	N	17	12	7	13	17	16	8
Tributary to Crooked Creek (UT 0.01), mined 43%	Mean	6.46	12	50	28	13.01	11	4.6
	Range	5.8-7.40	6-18	3-180	19-37	2-28	1-39	1.4-10
	N	14	11	6	7	14	12	8

TABLE 4. MEANS AND RANGES OF PROJECT DATA FROM NEW RIVER BASIN SITES

Location	Statistic	Constituent (mg/L)						
		pH	SO_4	Total suspended solids	Total hardness (as $CaCO_3$)	Alkalinity (as $CaCO_3$)	Acidity (as $CaCO_3$)	Total iron
Anderson Branch, mined 7.5%	Mean	6.18	6.2	13.3	6.98	6.28	3.05	0.69
	Range	5.20-6.56	0-12	0-100	5.29-9.16	4.42-10.5	1.78-9.40	0.05-7.3
	N	31	31	31	31	31	31	31
Lowe Branch, unmined	Mean	6.20	8.8	7.23	9.38	6.43	4.97	0.80
	Range	5.10-6.52	0-16	0-46	3.61-13.9	4.40-11.1	1.86-46.0	0.03-5.6
	N	39	38	39	39	39	39	35
Bowling Branch, unmined	Mean	6.36	6.13	16.0	7.54	7.09	3.39	1.19
	Range	5.73-6.69	4.4-9.6	0-260	4.78-11.5	4.4-9.20	1.46-9.40	0.011-11.0
	N	35	35	35	34	35	35	34
Bills Branch, mined 10%	Mean	6.79	25.3	1300	28.0	12.3	3.42	5.04
	Range	6.00-7.42	5-58	0-17,000	10.8-68.6	6.0-23.6	2.03-9.9	0.005-80.0
	N	46	46	46	45	46	46	46
Green Branch, mined 24%	Mean	7.17	133	1580	163	29.4	4.00	6.01
	Range	6.42-7.59	45-220	0-10,000	36.6-1100	18.01-37.4	2.34-12.1	0-41.0
	N	42	42	42	41	41	42	42
Indian Fork, mined 19%	Mean	6.61	201	232	279	13.6	4.54	9.73
	Range	5.15-7.62	2.5-250	0-3500	117-650	1.8-34.2	2.43-13.5	0.08-54.0
	N	45	44	45	45	45	45	44

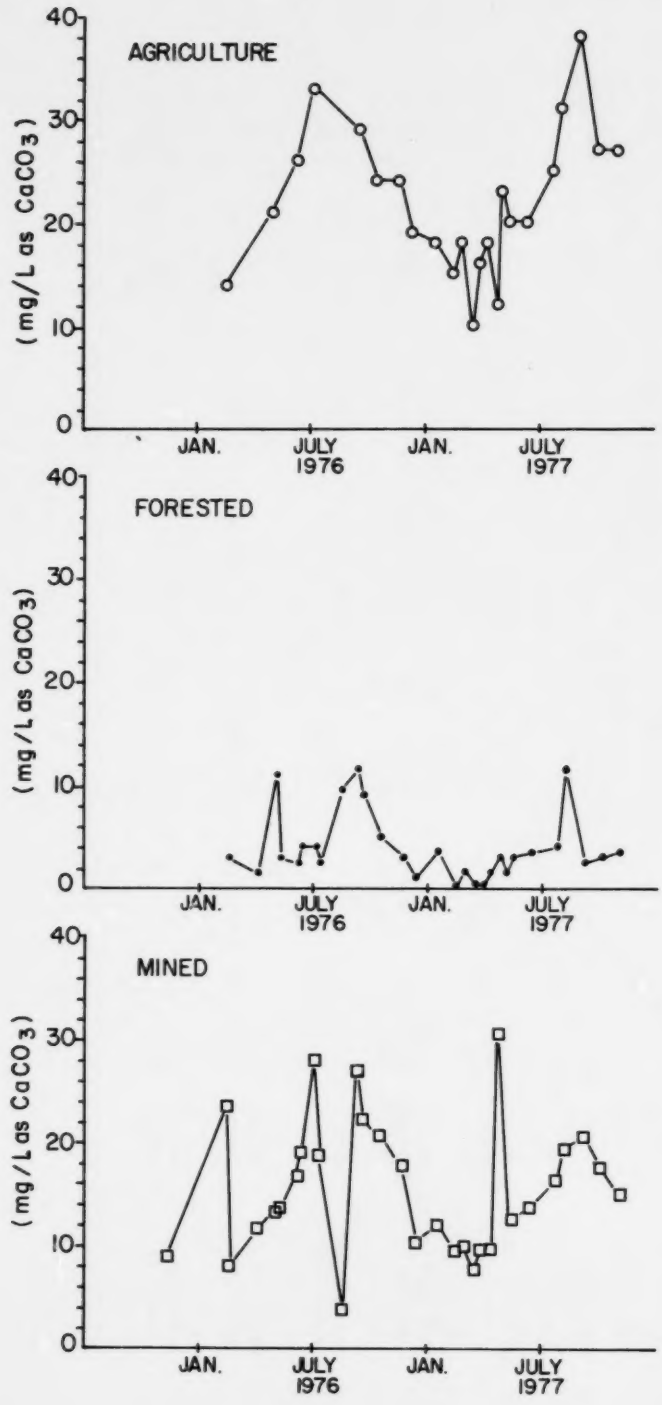

Figure 3. Alkalinity--Fentress County sites.

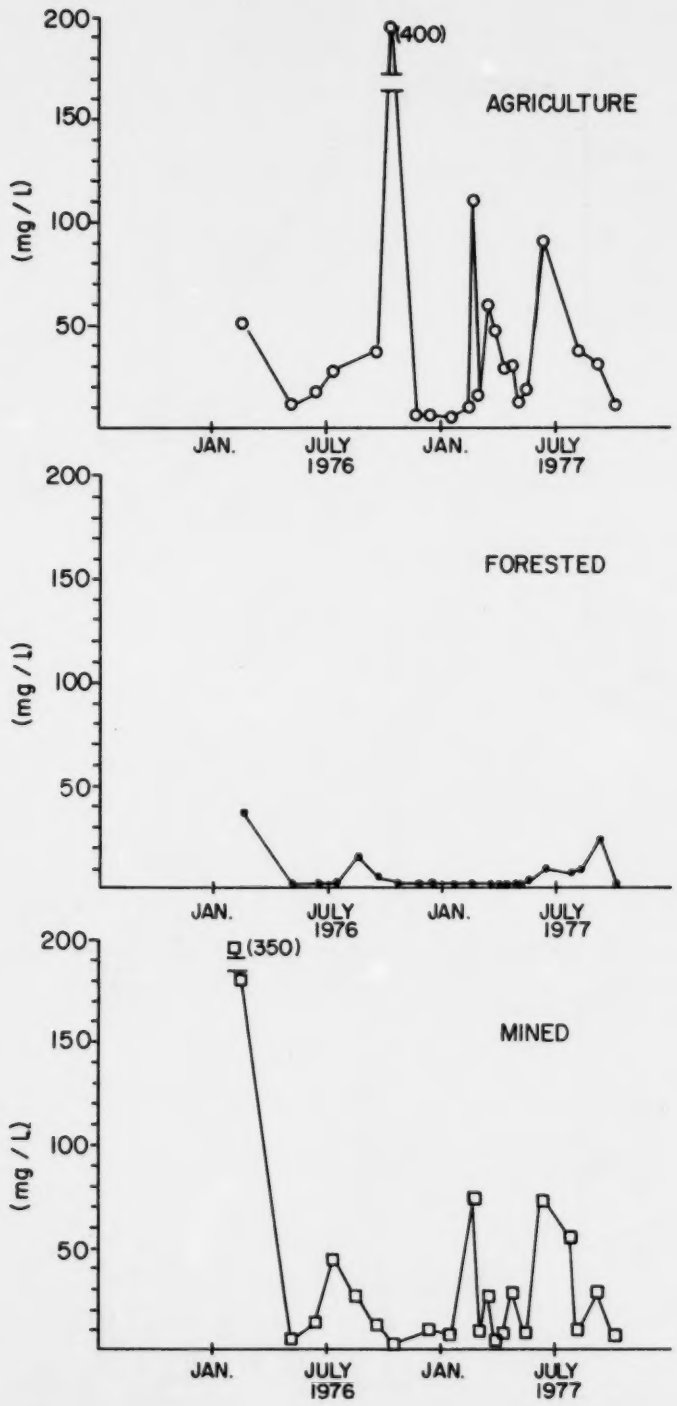

Figure 4. pH--Fentress County sites.

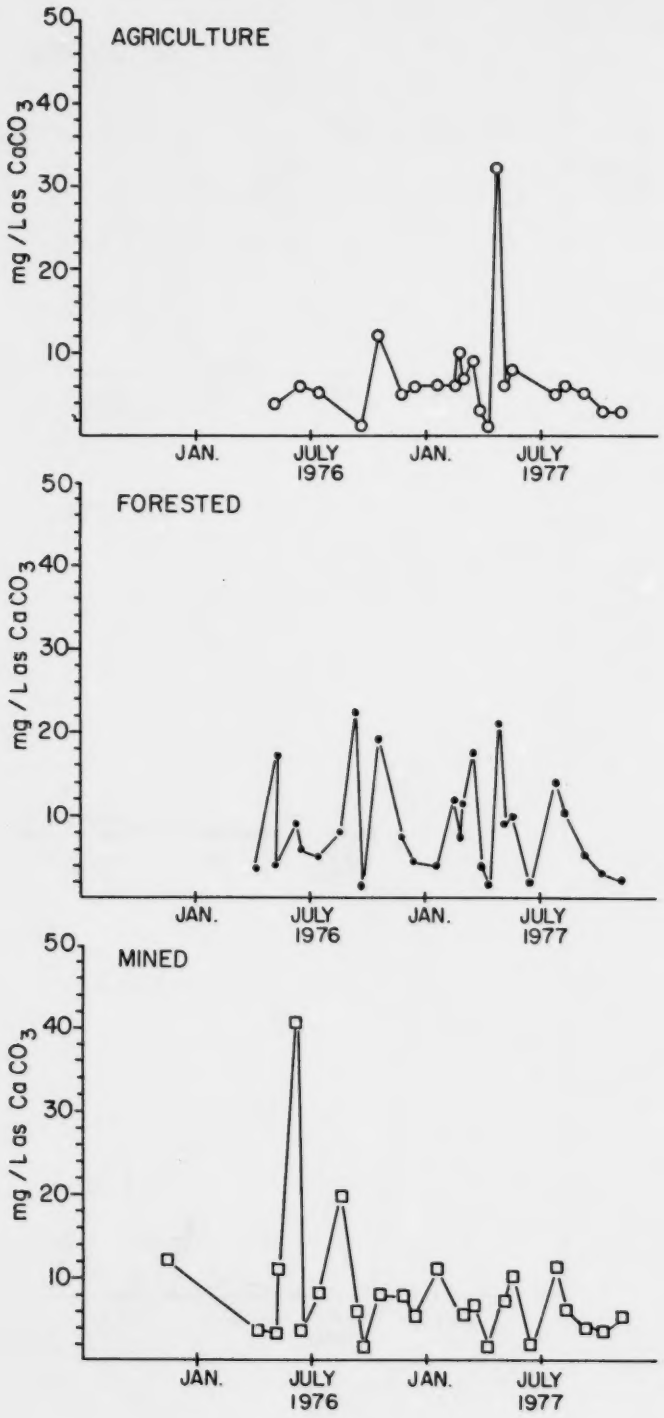

Figure 5. Acidity--Fentress County sites.

summer and early fall. Alkalinity exhibits a definite seasonality for Group A, with a peak occurring in the fall. Groups M and F show no similar trends.

Sulfate

Any production of acidity from oxidation of exposed pyrites will be accompanied by associated production of sulfate ion (Singer 1970; Silverman 1967). As a result of this phenomenon, increases in sulfate concentration are widely associated with mining activity. These increases may or may not be accompanied by decreases in pH or increases in acidity, depending on the amount and availability of strata with neutralizing potential. Table 3 and Figure 6 contain sulfate data from the Fentress County study sites; all sulfate values are relatively low. Mean sulfate concentrations appear to increase with mining by about 10 mg/L, whereas an increase of about 6 mg/L accompanies agricultural development.

These data indicate that little pyrite oxidation is occurring in the disturbed watersheds, as evidenced by the near-background level sulfate concentration at the mined watersheds. This is not inherently evident from pH, alkalinity, or acidity data because pyrite oxidation is sometimes followed by neutralization. Exposed pyrites will possibly be oxidized in the near future. A lag time between mining operations and increases in sulfate production, previously observed by Dyer (1976) and Plass (1976), is evident in data observed from the New River Basin studies of the University of Tennessee and TVA (Minear 1976).

Data for sulfate concentrations from the New River Basin (contour-mined) sites are presented in Table 4. In this case, sulfate concentrations increase markedly with mining. Sulfate concentrations are highest in Indian Fork (only 19 percent mined); lower, but still elevated by about 130 mg/L, in Green Branch (24 percent mined); and only slightly elevated (about 25 mg/L) in Bills Branch (10 percent mined).

The data in Indian Fork seem to be influenced by the existence of deep mines located within the basin. These data are part of a University of Tennessee study and are included here only for purposes of comparison. The higher sulfate and iron concentrations indicate that pyrite oxidation is occurring, but the relatively high alkalinity shows that neutralization is occurring. Mining began in Indian Fork Basin in 1952, in the Green Branch watershed in 1972, and in the Bills Branch watershed in late 1974. Short-term data (two years) indicate no such trends. Changes in mining and reclamation techniques also influence drainage quality. Bills Branch was largely mined and reclaimed under more stringent regulations.

Total Hardness

Caruccio (1976) suggested that the factor for determining the acidic character of mine drainage is the presence of calciferous materials in the overburden material. Contact of precipitation and interflow with newly exposed materials result in dissolution of soluble species such as calcium and magnesium carbonates. Total hardness (as calculated from calcium and magnesium) reflects this process.

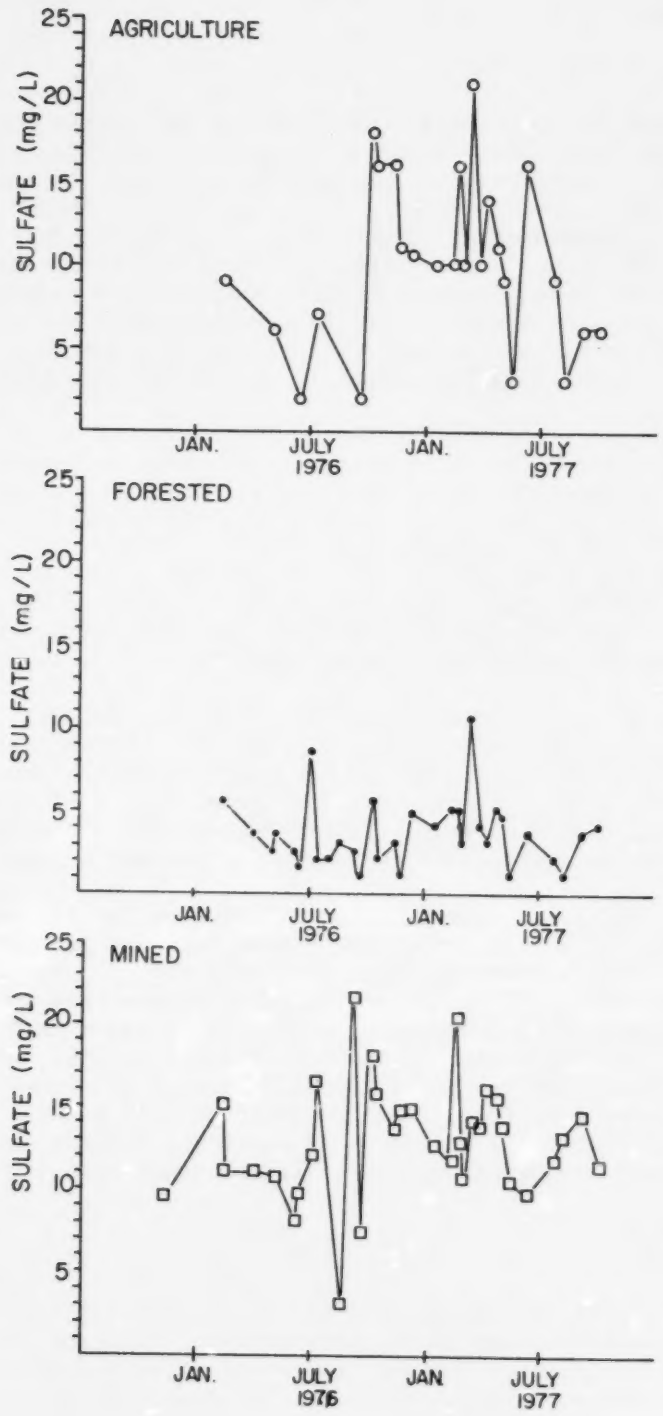

Figure 6. Sulfate--Fentress County sites.

Total hardness data from the area-mined sites are presented in Table 3 and Figure 6. Waters from forested areas are extremely soft, with hardness values (as $CaCO_3$) of about 10 mg/L. Waters draining agricultural areas are measurably harder, but still moderately soft, with hardness values of about 35 to 40 mg/L. Mined areas show similar concentrations. A trend of increasing hardness is evident for the mined and agricultural drainages.

Waters draining the forested areas in the New River Basin have hardness values very similar to those found at the Fentress County (area-mined) sites (Table 4); however, the similarity vanishes when mined areas are compared. The hardness values range from a mean of 40.3 mg/L on Bills Branch, a soft-water system; to 152 mg/L (as $CaCO_3$) on Green Branch, a moderately hard-water system; to 287 mg/L (as $CaCO_3$) on Indian Fork, a hard-water system. As expected, increases in total hardness roughly parallel increases in alkalinity in the Fentress County data (Table 3). The absence of this relationship at the New River Basin sites indicates that noncarbonate hardness is significant in these waters (Table 4).

Iron

Concentrations of total iron in strip mine drainages can be highly elevated, partly because of chemical and physical release of Fe^{+2} and Fe^{+3} in the oxidation of iron pyrites. Increases can also occur as a result of increased erosion and sediment transport.

Data from the area-mined sites are presented in Table 3 and Figure 8. Means and ranges for the mined and agricultural sites appear significantly higher than those for the control stations. No explanation of the two extremely high values for iron at the agricultural sites was evident. The one extremely elevated value for a mined site occurred during a period of heavy rainfall. Samples collected during periods of moderate to low flow, except for the two elevated values, suggest that mined and agricultural areas show no discernible trends, whereas samples from forested areas show an increase in total iron concentration during autumn. This increase in forested areas may reflect the input from leaf fall. During this period, water at the Long Branch control station, which showed the highest iron values, was visibly discolored, probably as a result of high concentrations of lignins and tannins. Iron values were high, exceeding the criteria proposed by EPA (1976a) for freshwater aquatic life (1 mg/L) 42 percent of the time.

Iron concentrations in streams draining the contour-mined sites were considerably higher than those found at the area-mined stations. Values presented in Table 4 reflect these elevated concentrations. Again, as in the Fentress County stations, the control stations also have higher iron concentrations, with values frequently exceeding the 1 mg/L criterion. Water at the station showing the highest concentrations, Indian Fork, is frequently discolored by iron precipitates, part of which probably come from abandoned underground mines in the basin.

Of the 319 samples collected for the Corps of Engineers in the New River Basin, 48 (15 percent) meet or exceed the 1.0 mg/L criterion. Thus, water quality in most parts of the basin may be limited as a result of these elevated iron concentrations.

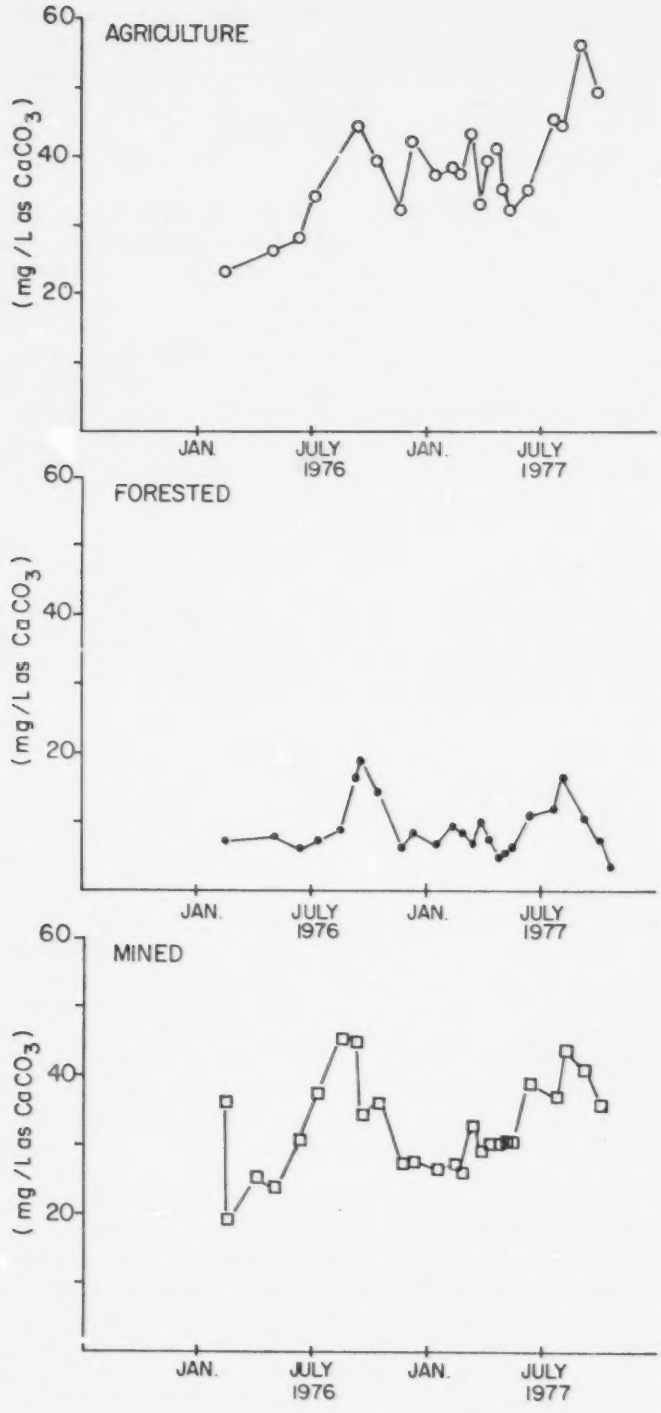

Figure 7. Hardness--Fentress County sites.

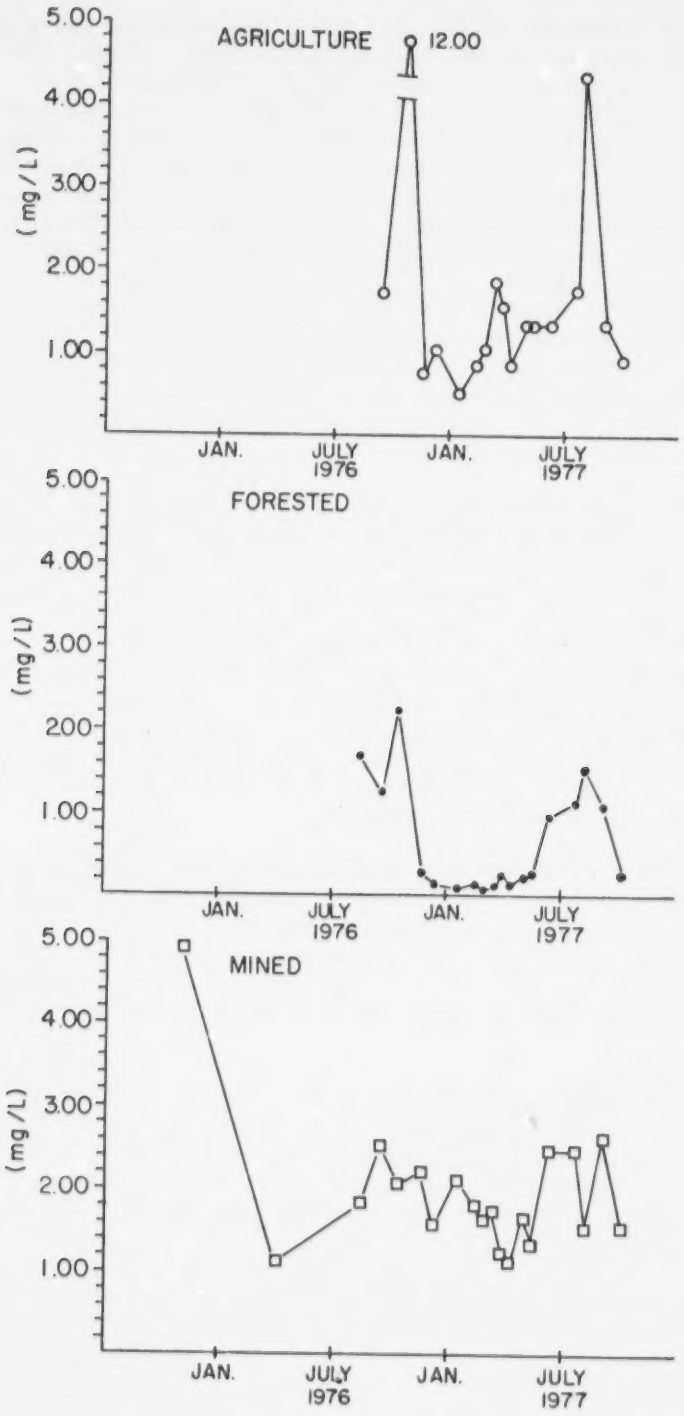

Figure 8. Total iron--Fentress County sites.

Total Suspended Solids

Control of suspended solids is widely regarded as the greatest water pollution problem in the United States (EPA 1976b). Suspended solids represent substances, organic (algae, biological floc, leaves, zooplankton, detrimental material) or inorganic (chemical precipitates or eroded soils), that are transported within the water column. Solids usually associated with mine drainages are inorganic. Iron flocs, during lower flows, can add significantly to concentrations of total suspended solids in mine drainage. A total iron concentration of 10 mg/L, if all iron is suspended, typically represents 19 mg/L of suspended solids [as $Fe(OH)_3$]. At station UT 0.01, suspended iron [as $Fe(OH)_3$] represented about 30 percent of the total suspended solids, whereas sandstone sediments typically contained about 2.4 percent iron (Degens 1965); the remainder represented iron precipitates. Many of the TSS concentrations are below 100 mg/L. During higher flows, when significantly more erosion and sediment transport occurs, the percentage of iron flocculent solids decreases.

Generally, the suspended solids in strip mine drainage result from rainfall washing disturbed soil into streams that drain the mine site. This problem is obviously a flow-related phenomenon, with the most serious events occurring during storm runoff.

Data presented in Figure 9 and Table 3 represent total suspended solids concentrations for the Fentress County sites. During low- to moderate-flow conditions (all samples except February), there is little difference between the agricultural station and mined-area samples. The samples representing forested areas are lower in all instances. Several samples (four mined, three agricultural) exceeded the new source performance standard of 70 mg/L for mine discharges.

These samples, however, reflect moderate- to low-flow conditions. Over 250 grab samples were collected at stations CC 15.9 and UT 0.01 during nine separate storms occurring between March 1977 and January 1978. Suspended solids concentrations ranged from 12 to 4000 mg/L at CC 15.9 and from 34 to 6300 mg/L at UT 0.01. Samples collected at the contour-mined sites show a larger difference between mined and unmined sites.

Almost 34 percent of the samples collected from streams draining mined areas were found to violate the suspended solids criteria; two undisturbed basins (Bowling Branch and Anderson Branch) also exceeded these criteria. This higher incidence of excessive concentrations of suspended solids probably results from the precipitous nature of the stream channel.

The data were analyzed for a possible relationship between suspended solids and turbidity (Minear 1976), but no significant relationship was found. The indication is that turbidity measurements do not adequately reflect suspended solids concentrations.

Because of the importance of rainfall-runoff relationships inherent to strip mine drainage, a series of storm runoff events have been sampled

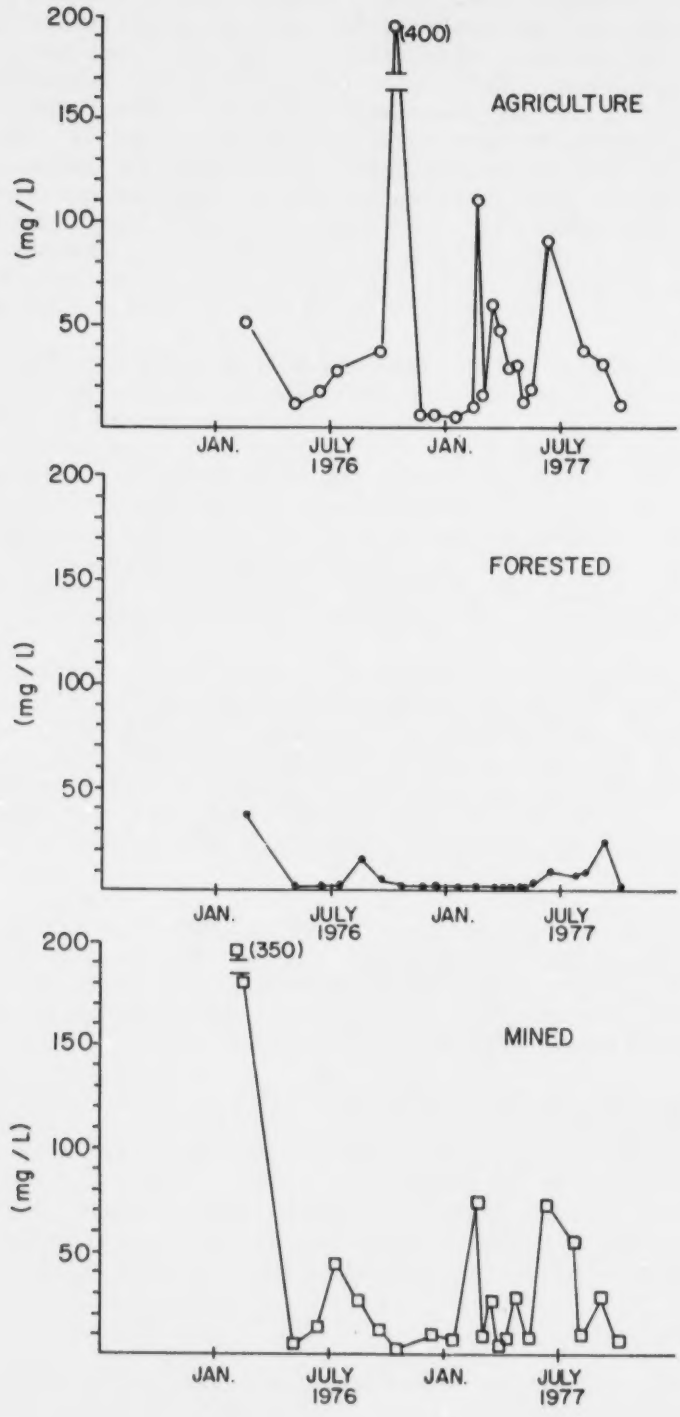

Figure 9. Total suspended solids--Fentress County sites.

by the University of Tennessee (Dunning 1977). The first of these events occurred on March 5-6, 1976. Samples were collected periodically across the hydrograph and analyzed for various constituents--total suspended solids, sulfate, alkalinity, turbidity, iron, manganese, calcium, and magnesium. Plots of concentrations and loads for total iron and suspended solids, along with the storm hydrographs for Indian Fork and Lowe Branch, are presented in Figures 10 and 11. These results are typical of other storms analyzed. Total flow for Indian Fork is considerably higher than for Lowe Branch, as expected because of the difference in watershed size. However, one would expect the hydrograph of the smaller watershed to be more pronounced since channel slopes are similar. This is not the case, indicating that mining may increase peak flows or that rainfall may have been heavier at Indian Fork watershed.

Concentrations of total suspended solids reach a maximum during the rise of the storm hydrograph, or about 2 h before the peak flow, and then fall off rapidly. This phenomenon illustrates an initial flush of readily available sediment, when the energy available for transport is high, during the rising portion of the hydrograph, followed by a rapid return to nearly normal concentrations. Loads of suspended solids are similarly abrupt. About 38 percent of the suspended load was transported during the hour surrounding the storm hydrograph peak; about 65 percent was transported during the peak hour and the hour following the peak. This illustrates the extreme transience of storm transport.

A different trend is observed for conservative substances such as sulfate. Sulfate concentrations generally decrease during the rising portion of the hydrograph and for some time past the peak, but essentially level off during the recession and begin to return to prestorm levels. This trend can be explained by simple dilution by surface runoff. Loadings of sulfate show a peak similar to, but less abrupt than, those for loadings of iron, showing a more gradual rise and decline.

The storm hydrograph at Lowe Branch did not show a dramatic rise and fall, as did that at Indian Fork. Also, sulfate concentrations were somewhat elevated across the hydrograph, with the dilution phenomenon never occurring. Loadings of sulfate reflected a definite peak with the storm hydrograph peak, followed by an elongated tailoff.

The suspended solids relationships at Lowe Branch were similar to those at Indian Fork in that concentrations during the storm runoff were higher than those during normal flow. The main difference lies in the elevated concentration obtained during early storm sampling at Lowe Branch, which indicates that, for small storms, somewhat higher concentrations occur earlier during the storm on this small, unmined watershed. These results possibly indicate inadequate sampling.

Trace Metals

A topic of concern in recent years has been those substances, especially trace metals, that may exert subtle, subacute effects on aquatic organisms after exposure to relatively low levels for long periods of time. Trace metals may affect organisms by uptake through

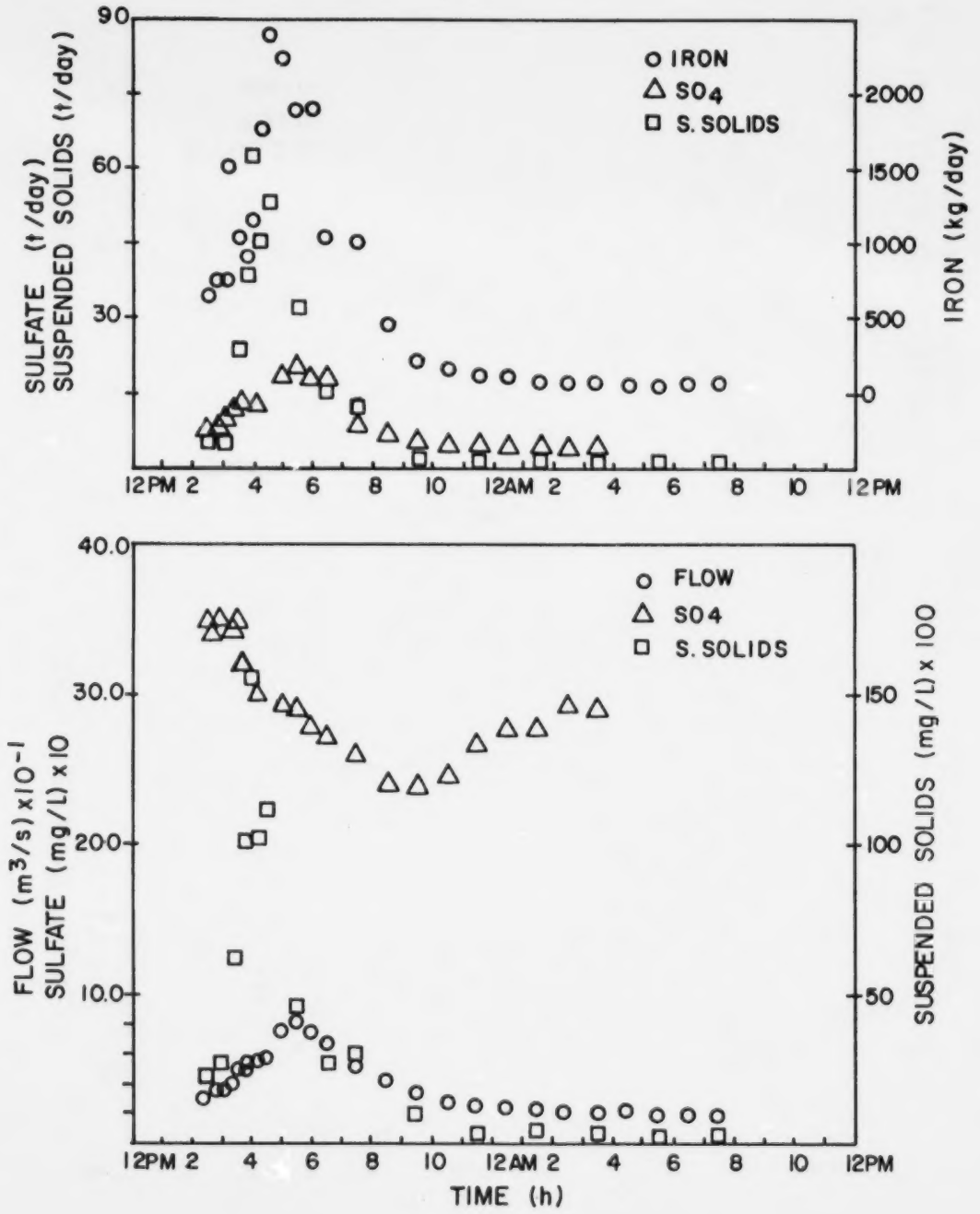

Figure 10. Lowe Branch loads and concentrations of iron, suspended solids, and sulfate.

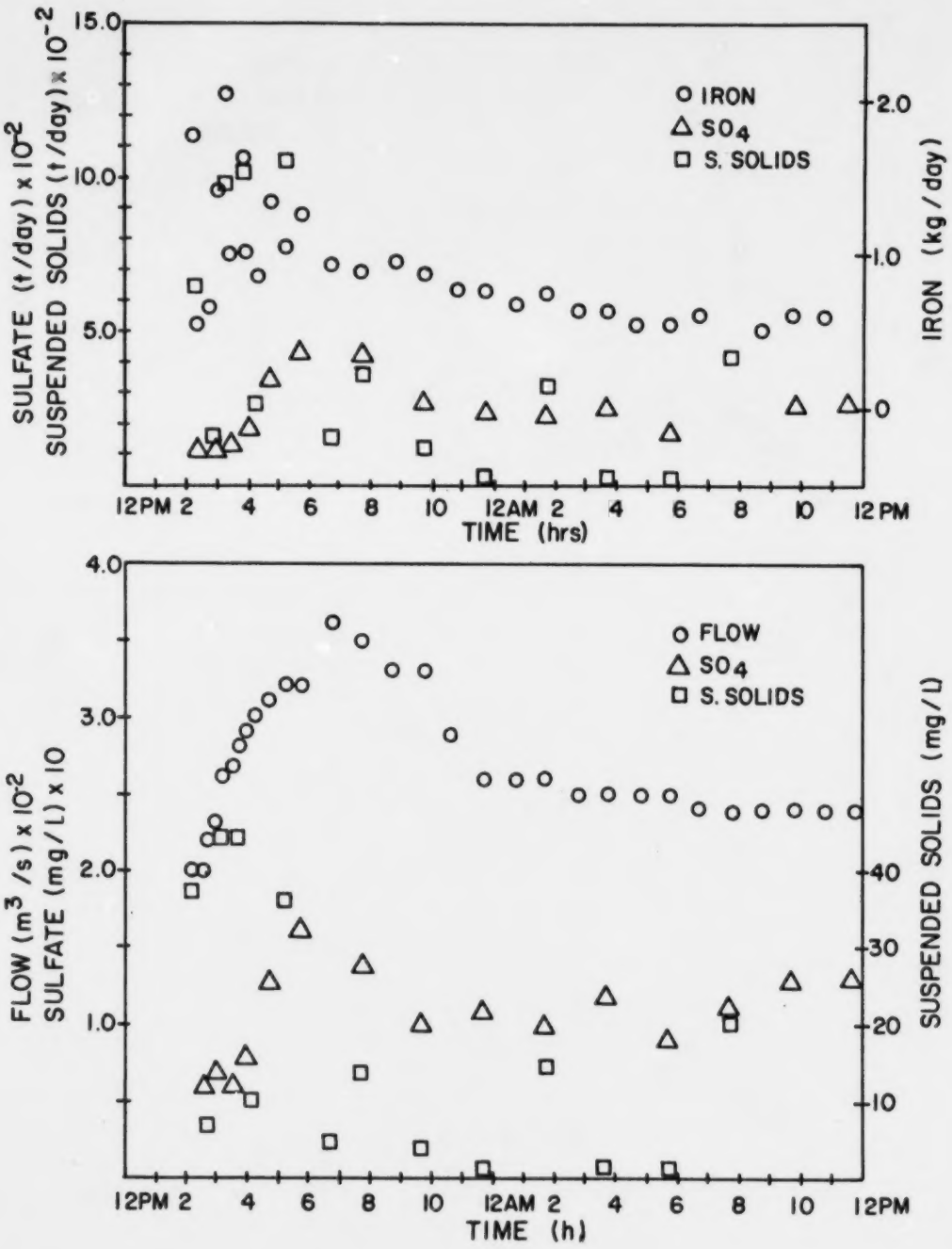

Figure 11. Indian Fork loads and concentrations of iron, suspended solids, and sulfate.

the food chain (biomagnification), direct intake or absorption (bioaccumulation), or influence on a segment of its food chain. In most cases, the mechanism of toxicity, the chemical form of the material, and the time and level at which chronic effects occur are unknown.

All these factors, along with the possibilities for synergism, complicate the establishment of a "safe" level for trace metals in the aquatic environment. Several attempts have been made at establishing an "across the board" set of water quality criteria. Among the most notable are Water Quality Criteria (FWPCA 1968), better known as the "green book," developed by the Federal Water Pollution Control Administration in 1968; the "blue book," Water Quality Criteria 1972 (NAS 1972), produced by the National Academy of Science for the Environmental Protection Agency; and finally, the "red book," Quality Criteria for Water (EPA 1976), published in 1976 by EPA as an alternative to the blue book recommendations. All these have received both approval and condemnation and remain controversial in their findings. Nevertheless, along with the U.S. Public Health Service's Drinking Water Standards (USPHS 1962), they are the most referenced and comprehensive sets of water quality criteria available today. For this reason, the "red book" recommendations, where applicable, will be used as a basis for determining the possible consequences of trace metals from strip mine drainages.

Selected trace metal data collected at the project watersheds are summarized in Table 5. Where concentrations were below detection limits, the detection limit was used for statistical purposes. Table 6 contains values for these metals at four points--larger rivers selected because of their large data bases rather than their similarity to the project watersheds--in the Tennessee Valley; these values provide an acceptable mode of comparison. The French Broad River at river mile 82.1 has a drainage area of 2800 km^2 that is largely forested. The river drains the Cherokee and Pisgah National Forests; Asheville, North Carolina, is the only city within the drainage area (Berthouex 1977).

The Holston River at river mile 118.4 is subject to significant waste discharges upstream from industries at Kingsport and along the North Fork Holston River. The drainage area at this point is 7450 km^2. The Tennessee River at river mile 602.3 is located at the tailrace of the Fort Loudoun Dam. The drainage area at this point is 24,700 km^2 and is influenced by both the Holston and the French Broad Rivers. Two cities--Knoxville, Tennessee, and Asheville, North Carolina--lie within the upstream drainage area. The Tennessee River at river mile 471.02 is the location of the tailrace of Chickamauga Dam. This point, well downstream from any major point source, represents a drainage area of 53,850 km^2.

Mean cadmium concentrations were similar for all streams, both mined and unmined. The highest concentration, which occurred only once, was 7 µg/L at Bills Branch. Only 1 of the remaining 102 samples exceeded the detection limit of 1 µg/L. These findings are consistent with values encountered at the Valley-wide stations. The maximum values, however, are above the "soft" water criterion of 4.0 µg/L for aquatic life (EPA 1976). The higher values do not appear with any regularity, and the means are all $\leq$2.0 µg/L.

TABLE 5. MEANS AND RANGES OF TRACE METALS DATA FROM PROJECT WATERSHEDS

Location	Statistic	Constituent (µg/L) Cadmium	Chromium	Copper	Lead	Nickel	Zinc	Manganese
				Area-mined region--Fentress County				
Lynn Branch (LY 0.4)	Mean	1.0	5.50	29.3	11.3	50.0	16.4	20
	Range	<1.0-1.0	<5.0-8.0	<10-90	<10-22	<50-50	<10-40	<10-40
	N	10	10	14	17	1	14	14
Long Branch (LB 4.6)	Mean	1.0	5.0	22.9	11.2	50.0	40.7	80
	Range	<1.0-1.0	<5.0-5.0	<10-50	<10-23	<50-50	<10-170	20-350
	N	10	10	14	17	1	14	14
Crooked Creek (CC 18.5)	Mean	1.11	5.11	33.9	11.1		21.5	120
	Range	<1.0-2.0	<5.0-6.0	<10.0-80	<10-22		<10-60	70-320
	N	9	9	13	16		13	13
Crooked Creek (CC 16.7)	Mean	1.0	8.44	27.7	12.2	50.0	18.5	190
	Range	<1.0-1.0	<5.0-33	<10-100	<10-37	<50-50	<10-40	70-850
	N	9	9	13	16	1	13	13
Crooked Creek (CC 15.9)	Mean	1.17	5.1	30.6	11.4	50.0	30.0	390
	Range	<1.0-3.0	<5.0-6.0	<10-90	<10-32	<50-50	<10-90	90-240
	N	12	12	16	19	3	16	16
Tributary to Crooked Creek (UT 0.01)	Mean	1.27	5.45	26.7	11.3	50.0	38.7	690
	Range	<1.0-4.0	<5.0-9.0	<10-60	<10-26	<50-50	<10-120	200-1000
	N	11	11	15	18	2	15	14
				Contour-mined region--New River Basin				
Green Branch	Mean	1.3	12	19	4.2	22	65	340
	Range	<1.0-20	<1.0-160	<1.0-180	<1.0-55	<1.0-240	<20-500	<40-1000
	N	71	42	61	53	55	32	77
Bills Branch	Mean	1.1	21	21	12	4.3	50	110
	Range	<1.0-7	<1.0-840	<1.0-320	<1.0-280	<1.0-50	<20-900	<40-1760
	N	78	59	68	57	67	33	78
Indian Fork	Mean	1.0	2.6	12	1.1	29	46	1200
	Range	<1.0-4	<1.0-10	<1.0-69	<1.0-13	<1.0-110	<20-130	<40-3700
	N	64	9	55	55	58	61	80
Anderson Branch	Mean	1.0	2.0	5.7	2.8	2.7	26	50
	Range	<1.0-2.5	<1.0-6.2	<1.0-45	<1.0-32	<1.0-11	<20-190	<40-580
	N	61	14	28	20	19	52	63
Lowe Branch	Mean	1.0	1.0	5.1	2.7	2.8	20	40
	Range	<1.0-1.0	<1.0-1.0	<1.0-48	<1.0-40	<1.0-25	<20-<20	<40-70
	N	48	10	38	23	21	28	60
Bowling Branch	Mean	1.0	2.	1.0	2.6	10.9	20	40
	Range	<1.0-2.0	<1.0-18	<1.0-1.0	<1.0-57	<1.0-100	<20-190	<40-580
	N	60	24	24	52	28	52	63

TABLE 6. MEANS AND RANGES OF TRACE METALS FROM POINTS IN THE TENNESSEE VALLEY

Location	Statistic	Constituent (µg/L)						
		Cadmium	Chromium	Copper	Lead	Nickel	Zinc	Manganese
Holston River Mile 118.4	Mean	2.0	5.0	26.2	10.0	50.0	33.6	120
	Range	<1.0-12	<5.0-<5.0	<10.0-700	<10.0-32	<50.0-<50.0	10.0-180	20.0-2900
	N	160	11	164	160	7	164	171
French Broad River Mile 82.1	Mean	1.0		36.0	11.0		94.8	72.7
	Range	<1.0-3		<10.0-570	<10.0-22		20.0-380	<10.0-1100
	N	92		92	92		92	92
Tennessee River Mile 602.3	Mean	2.0	5.0	29.2	11.0	50.0	15.4	55.0
	Range	<1.0-15	<5.0-<5.0	<10.0-840	<10.0-21	<50.0-<50.0	<10.0-90	20.0-160
	N	95	4	95	95	4	95	104
Tennessee River Mile 471.02	Mean	1.0	5.0	49.1	11.0	50.0	26.0	63.0
	Range	<1.0-9	<5.0-<5.0	<10.0-23	<10.0-52	<50.0-<50.0	<10.0-320	20.0-150
	N	95	4	95	95	4	95	103

Chromium concentrations for mined and unmined stations in the area-mined region have similar means, with one value at CC 16.7 exceeding 10 µg/L. All values for the Valley-wide stations were below the detection limit of 5.0 µg/L. At Green Branch only two samples exceeded the criterion for freshwater aquatic life (50 µg/L), whereas four samples exceeded the criterion for domestic water supply (EPA 1976). At Bills Branch, one sample exceeded the criterion for freshwater aquatic life, and three samples exceeded the domestic water supply criterion. Copper concentrations were also similar at mined and unmined sites in the area-mined region. Copper concentrations appeared higher at Bills Branch and Green Branch than at other stations. The mean values compare well with those at Valley-wide stations. However, maximum values for these stations are considerably higher than those from the study stations. All values were below the criterion for domestic water supplies (1000 µg/L), except for a single value at Tennessee River mile 471.02. This value, 2300 µg/L, was about five times as high as the next highest observation and almost 50 times as high as the mean value (49.1 µg/L).

Mining had little effect on lead in the streams in the area-mined regions. In the contour-mined New River Basin, Bills Branch, Green Branch, and an unmined station, Bowling Branch, exceeded the criterion for domestic water supplies (50 µg/L)--twice at the two mined stations and once at the unmined station. Concentrations at the Valley-wide stations exceeded the 50-µg/L criterion only once.

As for the previously discussed metals, nickel concentrations were not affected by mining in the area-mined (Fentress County) sites. Indian Fork appeared to have elevated nickel concentrations as compared with the remaining New River Basin stations. No concentrations at the Valley-wide stations exceeded detection limits.

Mean values for zinc appeared largely unaffected by mining at all sites. All values were well below the domestic water supply criterion of 5000 µg/L.

Values for manganese were elevated at all mined stations, except for Bills Branch. All stations, however, showed concentrations greater than the 50-µg/L criterion for domestic water supplies, but were lower than the 4-mg/L EPA effluent guidelines for manganese. Mean concentrations for all stations, for Lynn Branch in the area-mined region and Lowe Branch in the contour-mined areas, exceeded the 50-µg/L criterion. The most severely affected stations were the tributary to Crooked Creek (UT 0.01), station CC 15.9, Green Branch, and Indian Fork. Concentrations at these stations were well above the Valley-wide stations.

In summary, concentrations of all trace metals except manganese were largely unaffected by mining in the area-mined regions in Fentress County. Mining in the contour-mined regions seemed to increase some metal concentrations at selected sites, but the significance of these slight increases is questionable.

AQUATIC BIOTA

The fish populations in the streams around Jamestown were dominated by the creek chub (Semotilus atromaculatus). This species was found at every station, but its abundance was severely restricted at sites impacted by siltation.

The control station at Long Branch (LB 4.5) had fewer fish than any station sampled. The water at LB 4.6 was discolored, as if large amounts of tannins were present. A reduced pH was also observed, with values usually below 6, which could well account for reduced fish populations.

Several nonstream species, bluegill (Lapomis macrochirus), spotted bass (Micropterus punctulatus), and largemouth bass (Micropterus salmoides), were collected at the Crooked Creek stations. These fish probably escaped from breached farm ponds when the area was mined. The collections to date do not indicate any reproduction for the introduced species.

The other control site, Lynn Branch (LY 0.8), has a good population of creek chub and other minor stream species, including fathead minnows (Pimphales promelas) and blacknose dace (Rhinichthys atratulus). Continued sampling at LY 0.8 will provide the baseline data for establishing the transfer functions for developing the fisheries part of the ecosystem model for the area.

Preliminary analyses of the contents of fish stomachs indicate that the fish eat a wide variety of aquatic and terrestrial invertebrates. The principal food resource is aquatic dipteran midge larvae (Chironomidae), followed by springtails (Collembola) and aquatic mites (Arachnida). These resources constitute 31.1, 18.8, and 7.4 percent, respectively, of the individuals found in creek chub stomachs from the LY 0.8 site. Other sites show similar trends.

These data indicate that fish assemblages in the streams differ in the area, and these differences seem to be related to strip mine inputs in the basin.

Monthly biological sampling (qualitative and quantitative) of the attached algal (periphyton) and macrobenthic communities involved collection of 23 samples from each of five sites (CC 16.7, CC 18.5, CC 15.9, LY 0.8, and LB 4.6). These 23 samples included three Surber square-foot samples, collected from the dominant substrates present; one qualitative sample, composed of subsamples collected from all the major substrates present; three artificial basket substrates (4- by 4- by 2-in. cement blocks); four drift samples (dawn, day, dusk, night); one light trap; six sets of conservation webbing, an artificial substrate suitable to quite a few macrobenthic organisms; and five Plexiglas slides, an artificial substrate suitable for colonization by attached algae.

A summary of quantitative data collected with the Surber sampler is presented in Table 7. These data indicate that the macrobenthic biomass varies little among the five sampling sites. Station CC 18.5, a control site on Crooked Creek, contained the most constant quantity of biomass, which was attributed to the presence of a stable, homogeneous substrate

TABLE 7. QUANTITATIVE MONTHLY MACROBENTHIC DENSITY DATA (MARCH-OCTOBER 1976)--
FENTRESS COUNTY SITES

Station	Macrobenthic density (g/ft^2) by Surber square							
	Surber No. 1		Surber No. 2		Surber No. 3		Station	
	Insect	Noninsect[a]	Insect	Noninsect	Insect	Noninsect	Insect	Noninsect
Lynn Branch (LY 0.8)								
Range	0.01-1.18	0.04-2.28	0 -1.78	0.04-2.23	0.02-1.65	0 -	0 -1.78	0 -2.28
Mean	0.387	0.521	0.403	0.650	0.304	0.005	0.364	0.392
Long Branch (LB 4.6)								
Range	0 -0.204	0.05-0.29	0.01-1.94	0 -0.20	0.01-0.59	0.27-2.97	0 -1.94	0 -2.97
Mean	0.075	0.068	0.340	0.025	0.201	0.405	0.205	0.180
Crooked Creek (18.5)[b]								
Range	0.04-0.12	0 -0.05	0.21-1.30	0.22-0.72	0.05-0.19	0.01-0.73	0.04-1.3	0 -0.73
Mean	0.086	0.016	0.602	0.440	0.136	0.268	0.275	0.241
Crooked Creek (16.7)								
Range	0 -2.28	0.01-5.45	0 -0.62	0.02-1.5	0 -0.53	0 -0.72	0 -2.28	0 -5.45
Mean	0.408	0.779	0.253	0.208	0.214	0.090	0.291	0.359
Crooked Creek (15.9)								
Range	0 -0.23	0 -.076	0 -0.53	0 -2.18	0 - .60	0.04-7.10	0 -0.6	0 -7.1
Mean	0.046	0.010	0.092	0.492	0.154	0.899	0.097	0.467

[a]Includes crayfish, snails, and clams.

[b]Only sampled three times as of this report.

and a lack of siltation. Station CC 16.7, on the other hand, had insect biomass quantities ranging from 0.0 to 2.28 g/ft^2. This large variation in biomass probably resulted from a shifting, unstable, eroding substrate at this station. Station CC 15.9 contained the least mean quantity of insect biomass, but the greatest mean quantity of noninsect biomass, as a result of the large rubble substrate present. A species list of zoomacrobenthos data is presented in Appendix B.

The quantitative drift data collected to date are summarized in Table 8. Few trends are clearly discernible at this time. The greatest movement (drift) of insects per unit flow occurred in Long Branch. This conclusion may be biased, however, by the fact that flow data were available from this station only in the spring and summer, when many organisms were drifting. After August, the flow rate was too slow to measure, and thus the biomass collected could not be related to flow. Drift at station CC 18.5 may be biased in the opposite manner because data were collected only for those months when flow was relatively high and drift activity relatively low.

In general, the greatest amount of drift occurred at or around dusk, although Lynn Branch recorded its greatest drift at night. Drift was consistently greater at station CC 16.7 than it was downstream, indicating that organisms may be colonizing areas between two stations.

TABLE 8. QUANTITATIVE MACROBENTHIC DRIFT DATA COLLECTED MONTHLY (MAY-OCTOBER 1976)--FENTRESS COUNTY SITES

Station	Dawn	Day	Dusk	Night
Lynn Branch (LY 0.8)	0.24	6.45	14.4	32.0
Long Branch (LB 4.6)	12.4	35.0	87.0	9.0
Crooked Creek (18.5)	5.7	25.9	23.3	3.4
Crooked Creek (16.7)	29.0	1.3	68.0	16.0
Crooked Creek (15.9)	0.58	0.76	29.5	6.74

Data collected on the attached algal community (periphyton) and associated heterotrophic aufwuchs are summarized in Table 9. Chlorophyll *a* concentrations were used as a measure of algal biomass, although it might more appropriately be called a biomass "estimate," because the percentage chlorophyll per unit weight varies physiologically and taxonomically. Nevertheless, chlorophyll was used to estimate relative differences among similarly collected periphyton assemblages. The data indicate that Crooked Creek station CC 18.5 contained by far the greatest algal biomass per unit area, primarily as a result of two independent factors: (1) Much less erosion occurred in this control area, resulting in less suspended matter to scour away the algal communities; and (2) the forest canopy was more open at this site, allowing for greater incident radiation. Station CC 16.7 contained the least amount of algal biomass as a result of increased scouring and canopy. Canopy and turbidity were most likely the dominant factors limiting greater algal production at station CC 15.9, whereas light and nutrients were probably limiting production in the two small control streams, LY 0.8 and LB 4.6.

Station CC 18.5 (control) also contained the greatest amount of total attached aufwuchs (autotrophs plus heterotrophs). A large proportion of the aufwuchs was autotrophic, as indicated by the low ratio (0.48) of organic weight to chlorophyll.

Aufwuchs growing in surface waters that are relatively low in organic pollution are usually dominated by algae (if, of course, no other environmental factors are limiting). To obtain information on the physiological condition of the algal periphyton, the pheophytin index was also determined. Results of these determinations indicate that the algal communities at station CC 18.5 were the most healthy (least percentage of pheophytin), whereas those at stations LB 4.6, LY 0.8, and CC 15.9 were the least healthy.

TABLE 9. MONTHLY PERIPHYTON DATA (APRIL-OCTOBER 1976)--FENTRESS COUNTY SITES

Station	Chlorophyll a (mg/L)	Ash-free organic wt. (g)	Autotrophic[a] index	Pheophytin[b] index
Lynn Branch (LY 0.8)	0.36	0.014	4.40	1.18
Long Branch (LB 4.6)	0.69	0.012	2.05	1.17
Crooked Creek (CC 18.5)	8.82	0.040	0.48	1.55
Crooked Creek (CC 16.7)	0.29	0.011	2.09	1.31
Crooked Creek (CC 15.9)	0.53	0.026	3.24	1.18

[a]Ash-free organic wt. (mg/m^2) divided by chlorophyll a (mg/m^2).

[b]Unacidified OD^{663} divided by acidified OD^{663}.

OVERBURDEN ANALYSIS

Chemical quality of drainage from strip-mined lands is a function of the geology of the disturbed areas. Exposure of substrate below the weathered zone results in chemical weathering of previously unavailable materials.

The processes primarily responsible for establishing the acidic or alkaline character of the drainage are (1) leaching of previously unexposed neutralizing substances, such as calcium or magnesium carbonates; (2) exposure of mica or clay minerals, which serve as a buffer by reacting with acid from pyrite oxidation; and (3) oxidation of pyrites to form sulfuric acid and ferrous iron. Weathering also results in leaching of materials such as iron, manganese, sulfates, and trace metals, from the newly exposed and weathered overburdens. The amount of leached material is a function of the amount of overburden exposed, the replacement sequence of overburden, the amount and distribution of pyrites and trace metals in the overburden, and the amount of water available for leaching and transport.

When pyrites are exposed to the atmosphere, they are chemically and biologically oxidized. By-products of this oxidation include ferrous iron, sulfate, and acidity. Oxidation is accomplished by the reaction sequence,

$$2\ FeS_2(s) + 7\ O_2 + 2\ H_2O \rightarrow 2\ Fe^{+2} + 4\ H^+ + 4\ SO_4^{-2}. \qquad (1)$$

This ferrous iron then undergoes oxidation to the ferric state in a rate-limiting step:

$$4\ Fe^{+2} + O_2 + 4\ H^+ \rightarrow 4\ Fe^{+3} + 2\ H^+ + 2\ OH^-. \qquad (2)$$

Ferric iron then hydrolyzes to form insoluble ferric hydroxide, thus producing more acidity,

$$Fe^{+3} + 3\ H_2O \rightarrow Fe(OH)_3(s) + 3\ H^+, \qquad (3)$$

or oxidizes pyrite directly, thus producing more ferrous iron and acidity,

$$FeS_2(s) + 14\ Fe^{+3} + 8\ H_2O \rightarrow 15\ Fe^{+2} + 2\ SO_4^{-2} + 16\ H^+. \qquad (4)$$

A preliminary indication of the character of the overburden is illustrated by the concept of the acid-base balance developed by Smith et al. (1974). The potential for a mine spoil to provide acidity can be measured or predicted directly from pyritic sulfur concentrations. The potential for a mine spoil to produce alkaline materials can also be measured directly, but not predicted by other measurements. When these measurements are expressed in similar units, they can be summed to give the acid or alkaline potential for individual strata. These strata potentials can be summed to give a similar potential for the entire sequence.

Other characteristics important in determining the quality of water draining the spoil are cation exchange capacity (CEC) and soil pH.

To collect representative data for individual strata and to facilitate the comparison of data, cores were drilled in selected study watersheds. These cores were obtained at four locations within Fentress County (Figure 1) and at three locations within the New River Basin (Figure 2).

Cores JA1 and JA2 (numbers 1 and 2 in Figure 1), collected in Fentress County, were in undisturbed land drained by Crooked Creek (upstream from stations CC 15.9 and UT 0.01); core JA3 (number 3 in Figure 1) was taken from mine spoil upstream from station UT 0.01; and the final core in

Fentress County, G1 (number 4 in Figure 1), was collected near Grimsley in an undisturbed area drained by Long Branch (station LB 4.6). All cores were taken so as to represent the strata overlying the Nemo coal seam, which is the primary coal mined in the Crooked Creek watershed.

The cores collected in the New River Basin were all taken from within the Anderson Branch watershed. Each core represents a seam, or group of seams that can be mined simultaneously, and contains 20 to 30 m of overburden. One core, NR3 (number 1 in Figure 2), was taken to represent mining disturbance from developing the Pewee and Walnut Mountain coal seams. The core contains strata from elevations of 770 to 800 m (770 m is the top of the Pewee seam, and the Walnut Mountain seam is about 9 m below). The coals and the intervening strata were not recoverable.

A second core, NR2 (number 2 in Figure 2), was taken to represent disturbance from developing the Big Mary coal seam and contains strata from elevations of 670 to 701 m. The strata run from the coal seam upward.

A final core, NR1 (number 3 in Figure 2), was taken to represent disturbance from developing the Jellico coal seam and contains strata from elevations of 478 to 519 m. The Jellico coal is about 30 cm thick and occurs at 481 m below the existing surface.

After the core samples were logged (see Appendix C), composite samples were taken to represent strata that were lithologically similar. The characteristics used in determining similarity included color, texture, and mineral composition. Much of the core was unrecoverable. This loss represents unconsolidated material that was "washed out" as a part of the core drilling operation.

About 220 g of each composite was ground to pass through a No. 50 sieve, yet be retained by a No. 100 sieve, and was analyzed for total sulfur, pyritic sulfur, cation exchange capacity (CEC), calcium carbonate, soil pH, potential acidity with peroxide, and total neutralization potential. Composite samples of about 2 kg, ground to pass through a No. 10 sieve, were retained for leaching studies. The core logs are presented in Appendix C.

Bar graphs depicting volume-weighted mean values for each core are presented in Figures 12 and 13.

The cores taken from Fentress County are dominated by sandstones, with intermittently occurring claystones and shales. Figure 12 contains weighted mean values for the analyses performed on individual strata of Fentress County cores. The means are weighted on the basis of depth of the individual strata.

The CECs were similar for all cores, ranging from 7.4 to 14.0 milliequivalents (meq) per 100 g. Concentrations of calcium carbonate, ranging from 0.13 to 0.46 meq per 100 g, indicate that the soils contain a relatively high percentage of exchangeable magnesium, potassium, or sodium. However, this soil content has not been reflected in water quality data for which Mg:Ca, K:Ca, and Na:Ca ratios are comparable to values obtained elsewhere.

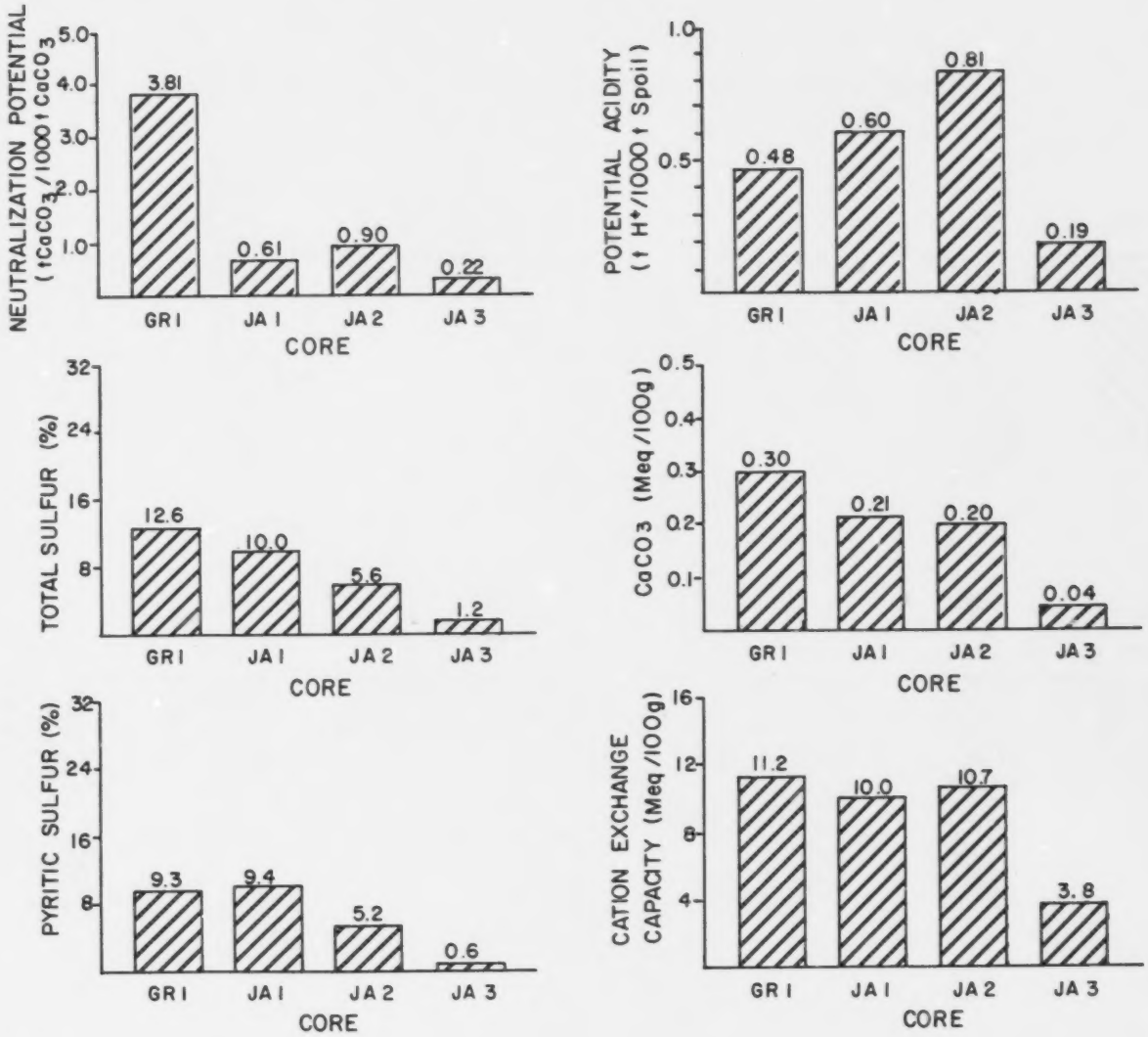

Figure 12. Strata analyses--Fentress County sites.

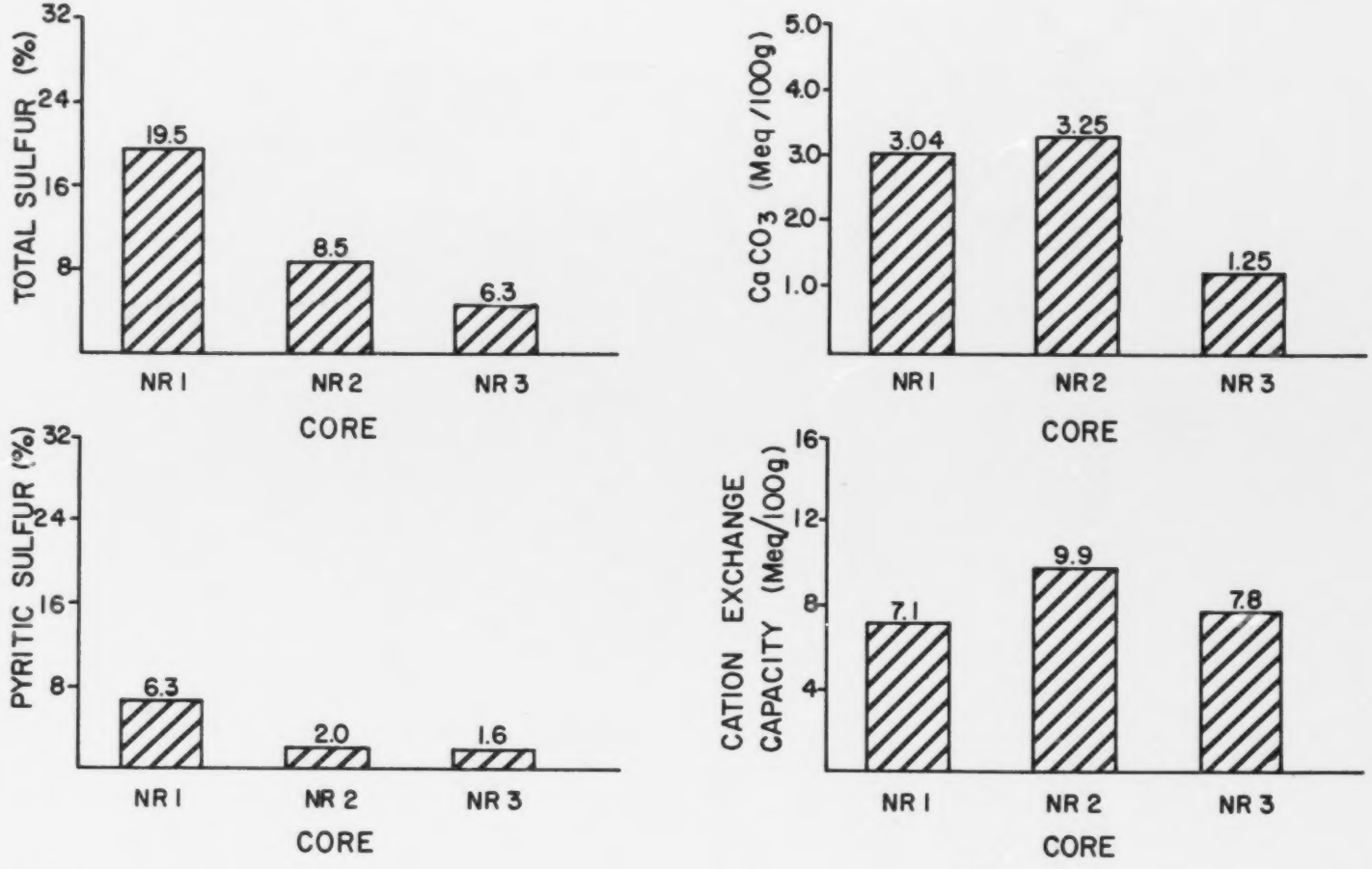

Figure 13. Strata analyses--New River Basin sites.

Neutralization potentials are slightly higher than potential acidities for all cores, thus adequately reflecting the alkaline character of the drainage. Total and pyritic sulfur values are very low, which explains the low values for potential acidity. Pyritic sulfur makes up 50 to 75 percent of the total sulfur.

The data indicate that cores JA1, JA2, and JA3 are very similar and that little weathering has occurred in the mine spoil (core JA3). Core G1 contains significantly greater neutralization potentials.

New River Basin cores are dominated by siltstones and shales, with core NR3 containing the only significant sandstone layers. Figure 13 contains results of chemical analyses on the New River Basin cores. Values for neutralization potential and potential acidity are not available at this time. Unlike the Fentress County cores, the percentage of exchangeable calcium to CEC is typical for many soil types. Significant amounts of total or pyritic sulfur were not found in any cores.

Values for neutralization potential and for calculated and measured potential acidities with peroxide were used to produce acid-base balances for the Fentress County core. The results are presented in Table 10. The only instance for which good agreement occurs is at core JA2. All results except for the calculated balance for core JA1 indicate an excess of neutralizing material. Water quality data suggest that an excess should exist in all cores. If the coal were not included, the calculated balance for this core would be only slightly acid at 0.06 ton $CaCO_3$ equivalent per 1000 tons of spoil. Differences between individual measured values and calculated values were quite large. A correlation analysis produced an r value of 0.271. The mean value for the measured values of potential acidity with peroxide was 0.70, with a standard deviation of 0.33, whereas the mean and standard deviation were 1.90 and 3.51 for the values calculated from pyritic sulfur. This indicates that, on the average, values predicted from pyritic sulfur contents are higher than values measured in the laboratory. This is consistent with the findings of Caruccio (1976), who has shown that framboidal (reactive) pyrite, rather than total or pyritic sulfur contents, dictates the amount of acid production. Values of excess neutralization potential (Table 10), calculated by using data from the acidity with peroxide procedure, indicate that all stations have a positive excess neutralization potential. This agrees with the findings of increased pH, alkalinity, and hardness in the mined streams.

HYDROLOGICAL MODEL STUDIES

One advantage of the regionalized approach being taken with the hydrological models is that data from other sources can be used to calibrate and verify the models. For example, a paper by Betson (1975) describes simulations made at five quite different watersheds using regionalized relationships developed for the continuous streamflow model that is being used in this project. The following section describes some work that has been done to date with off-project data.

TABLE 10. ACID-BASE BALANCE FOR FENTRESS COUNTY STRATA

Core	Strata	Neutralization potential[a]	Acidity with peroxide[a]	Calculated acidity[a]	Excess neutralization potential		Individual strata depths		Corrected excess neutralization potential		Summation of excess neutralization potential	
					Using acidity with peroxide[a]	Using calculated acidity[a]	Measured value (%)	Normalized (%)	Using acidity with peroxide[a]	Using calculated acidity[a]	Using acidity with peroxide[a]	Using calculated acidity[a]
JA1	1	0.8	0.52	0.62	0.28	0.18	39.2	51.7	0.145	0.093		
	2	0.6	0.66	0.31	-0.06	0.29	17.0	22.4	-0.013	0.065		
	3	<0.3	0.98	11.9	-0.68	-11.6	7.3	9.6	-0.065	-1.11		
	4	1.5	1.0	2.81	0.5	-1.31	12.3	16.2	0.081	-0.212		
											0.148	-1.16
JA2	1	<0.3	1.5	6.87	-1.2	-6.57	3.9	4.4	-0.053	-0.289		
	2	<0.3	0.63	0.31	-0.33	-0.01	45.5	51.7	-0.171	-0.005		
	3	1.8	0.56	0.31	1.24	1.49	29.4	33.4	0.414	0.498		
	4	0.8	0.55	0.31	0.75	0.49	2.7	3.1	0.008	0.015		
	5	2.3	1.3	1.25	1.0	1.05	4.4	5.0	0.050	0.053		
	6	0.8	1.1	1.87	-0.3	-1.07	2.1	2.4	-0.007	-0.026		
											0.241	0.246
JA3	1	0.5	0.38	<0.31	0.12	0.19	8.3	8.3	0.010	0.016		
	2	0.8	0.94	<0.31	-0.14	0.49	8.3	8.3	-0.012	0.041		
	3	1.3	0.36	<0.31	0.94	0.99	8.3	8.3	0.078	0.082		
	4	1.5	0.29	<0.31	1.21	1.19	8.3	8.3	0.100	0.099		
	5	0.3	0.34	0.31	-0.04	-0.01	8.3	8.3	-0.003	-0.001		
	6	0.4	0.86	0.62	-0.46	-0.22	8.3	8.3	-0.038	-0.018		
	7	<0.3	1.5	<0.31	-1.2	0.29	8.3	8.3	-0.100	0.024		
	8	<0.3	0.33	<0.31	-0.03	0.29	8.3	8.3	-0.002	0.024		
	9	<0.3	0.30	0.93	0	-0.63	8.3	8.3	0	-0.052		
	10	<0.3	0.86	1.87	-0.56	-1.57	8.3	8.3	-0.046	-0.130		
	11	1.1	0.32	0.62	0.78	0.48	8.3	8.3	0.065	0.040		
	12	1.1	0.62	0.31	0.48	0.79	8.3	8.3	0.040	0.066		
											0.092	0.191
G1	1	2.2	<0.05	<0.31	2.15	1.89	45.2	61.8	1.33	1.17		
	2	7.0	0.95	0.31	6.05	6.69	9.2	12.6	0.762	0.043		
	3	10	0.62	13.75	9.38	-3.75	4.6	6.3	0.591	-0.236		
	4	1.6	0.69	1.87	0.91	-0.27	14.2	19.4	0.177	-0.052		
											2.86	1.73

[a]Tons $CaCO_3$ equivalent/1000 tons spoil.

Model Testing Using Beaver Creek, Kentucky, Watershed Data

Musser et al. (1970) describe a pioneering study conducted in Beaver Creek watershed in Kentucky that was aimed at quantifying the effects of strip mining on hydrology. Some of the project data are published, and most are available from the USGS (Louisville, Kentucky, office). Streamflow recorder charts, precipitation abstracts for selected storms, and daily rainfall data for several years were obtained from the USGS for use in testing present modeling capabilities (water quality and daily streamflow data were published). Two watersheds were involved: (1) Helton Branch, a 2.2-km^2 control watershed that was 91 percent forested; and (2) Cane Branch, a 1.7-km^2 watershed, 10.4 percent of which had been strip-mined by 1959.

Figure 14 shows observed streamflow vs. that simulated with a continuous daily streamflow model for the water year 1961-62 at Helton Branch; model parameters predicted from previously developed regionalized relationships were used. The observed volume of runoff for the water year was 62.0 cm over the watershed, the simulated volume was 58.8 cm, and the model explained 66 percent of the daily flow variance. These same simulated values would have been obtained even if no stream gage data had been available.

Figure 15 shows the results obtained at Cane Branch watershed. The observed streamflow totaled 65.5 cm, whereas the simulated streamflow totaled 57.4 cm, with the model explaining 76 percent of the variance. Surprisingly, the results obtained with the model are almost as good at Cane Branch as they were at the unmined Helton Branch. This indicates that the effect of mining 10.4 percent of Cane Branch has not markedly affected daily streamflows (beyond that accounted for by the model), and that the existing regionalized relationships for this model are reasonably adequate. Whether these relationships will remain adequate as the percentage of watershed mined increases or if the watershed is area-mined remains to be tested.

The regionalized relationships that had previously been developed for the storm hydrograph model being used at the project were also tested with the Beaver Creek watershed data. This model had not previously been calibrated with data from watersheds in the Cumberland Plateau physiographic province (where Appalachian coal is located). Results indicated that the regionalized relationships are not adequate in this province, even for unmined watersheds. Storm hydrograph data for additional watersheds have been obtained to improve the regionalized relationships.

Tests of Background Nonpoint Source Water Quality Model

A regionalized, mineral water quality model for nonpoint sources has been previously developed which can be used to simulate the background quality expected from natural areas (areas without major pollution sources). This model, described by Betson and McMaster (1975), was extended to include additional constituents, as described by Betson (1976). This model was also tested on the Beaver Creek watershed data. Table 11 summarizes the observed data for many constituents for both Helton Branch and Cane Branch along with the model simulations. The

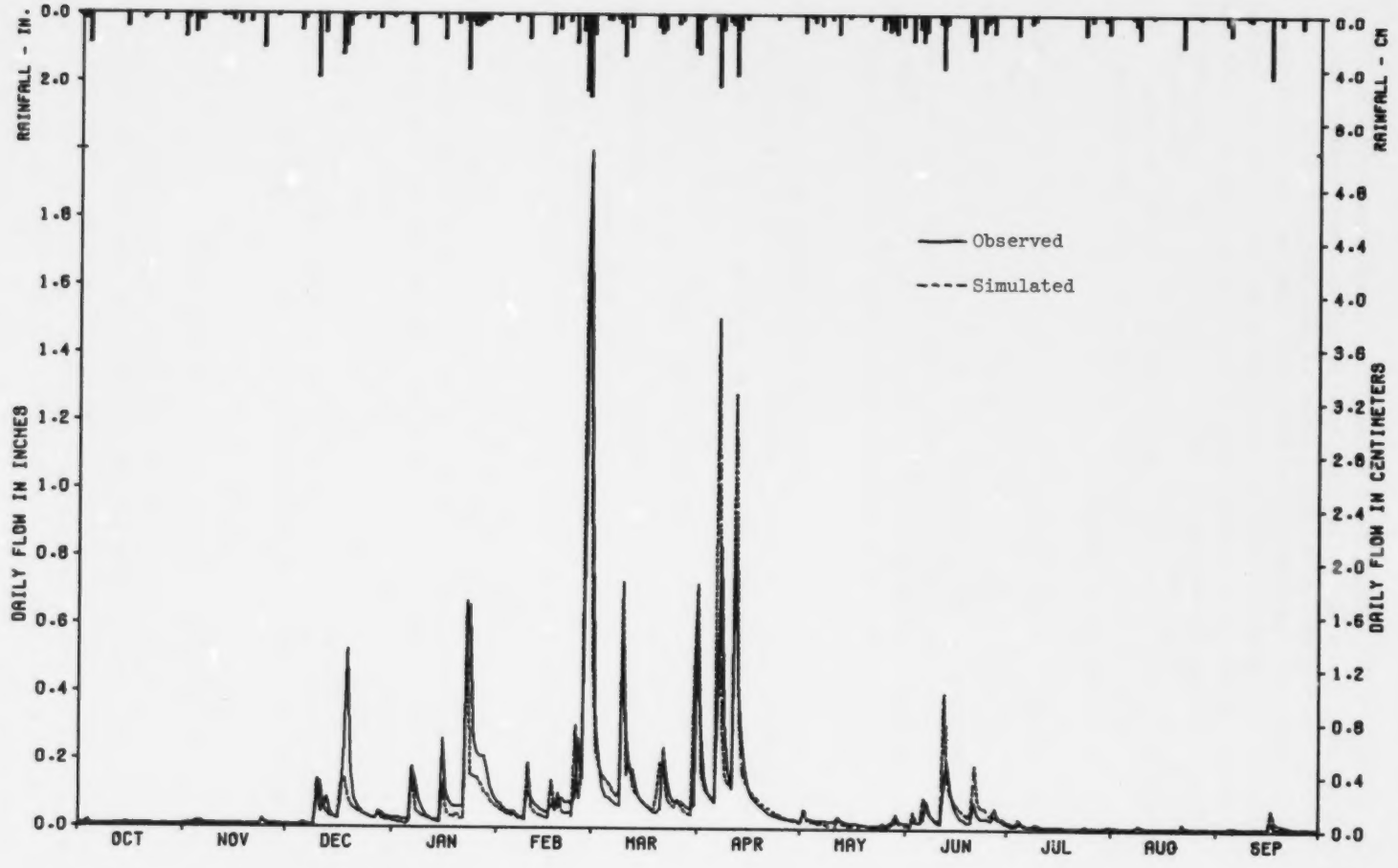

Figure 14. Helton Branch at Greenwood, Kentucky--observed vs. simulated flow.

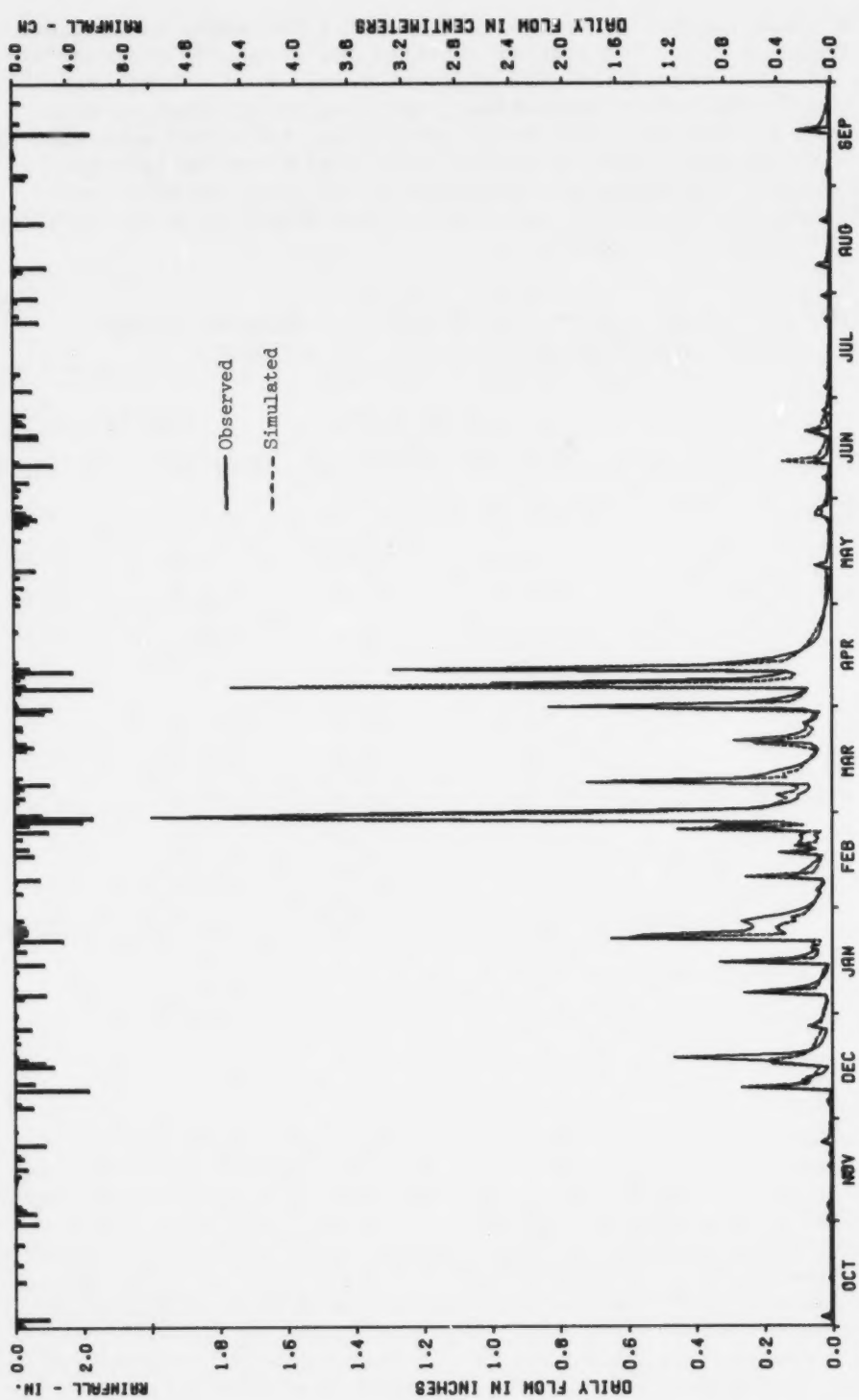

Figure 15. Cane Branch at Parkers Lake, Kentucky--observed vs. simulated flow.

results obtained for Helton Branch indicate that the model is adequate for most constituents. The results obtained for suspended sediment are not good, but this regression-type sediment model could not be used in this project in any case. In contrast, the results obtained at Cane Branch are quite different when water quality in this mined watershed is compared with the model that simulates water quality in background (unmined) areas. The elevated concentrations of iron, sulfate, sediment, and dissolved solids, in particular, that result from mining will be built into the project models.

TABLE 11. WATER QUALITY SIMULATIONS--TVA NONPOINT SOURCE WATER QUALITY MODEL--BEAVER CREEK WATERSHED

	Helton Branch[a]		Cane Branch[b]	
Constituent	Observed	Simulated	Observed	Simulated[c]
SiO_2, mg/L	5.2	5.6	-	5.7
Fe, mg/L	0.14	0.02	5.4	0.02
HCO_3, mg/L	10.0	15.0	1.0	16.0
SO_4, mg/L	5.0	5.8	280.0	6.2
Cl, mg/L	1.3	1.3	-	1.4
TDS, mg/L	25.0	33.0	370.0	35.0
$CaCO_3$, mg/L	11.0	18.0	130.0	20.0
Specific conductivity, µmhos	32.0	48.0	662.0	57.0
pH	6.6	6.8	3.6	6.7
Suspended solids, tons	30.0	107.0	1250.0	83.0

[a]91% forest control watershed.

[b]10.4% of area strip-mined.

[c]Simulated as unmined.

One other test was made of the background water quality model for nonpoint sources. Initial data collected on the project indicated that the iron and sulfate values in the control watersheds might considerably exceed values simulated with the model. Although a few data from the Cumberland Plateau province had been included in the model calibration, they were insufficient. A compilation of watersheds located in the Cumberland Plateau province was therefore obtained from STORET. The watersheds were reviewed to locate those unaffected by mining; a total of five (in addition to those used in the original model calibration) were found. The model was then used to simulate average concentrations for each constituent, which were compared with the observed data. The results, shown in Table 12, indicate that the existing model seems to be

TABLE 12. TEST OF TVA BACKGROUND NONPOINT SOURCE WATER QUALITY MODEL AT UNMINED WATERSHEDS

Watershed	Drainage area (km^2)	Percent forest	Constituent (mg/L)														
			pH	SO_4	Total Fe	Diss. Fe	TDS	Cl	Na	Total PO_4	Diss. PO_4	NH_3 N	Org. N	SiO_2	Total Mn	Ca	Mg	K
Obed River near Crossville, TN	31	98																
Observed			7.0	5.2	1.1	0.7	58	3.3	1.4	0.07	0.04	0.08	0.4	2.0	0.40	5.7	0.8	1.7
Simulated			6.8	5.2	0.6	0.02	30	1.1	1.1	0.1	0.06	0.02	0.2	5.5	0.06	5.0	0.7	0.8
Clear Creek near Lansing, TN	396	85																
Observed			7.0	6.1	0.3	0.08	-	3.1	1.0	0.02	0.01	0.02	0.2	2.6	0.02	2.4	0.9	1.2
Simulated			6.8	6.2	0.6	0.02	-	1.4	1.3	0.1	0.06	0.02	0.2	5.7	0.06	6.2	1.0	1.0
Greasy Creek near Gobey, TN	36	100																
Observed			7.0	8.3	0.6	0.14	21	1.9	1.4	0.03	0.02	0.02	0.2	4.7	0.02	1.4	1.4	-
Simulated			6.7	5.1	0.6	0.03	30	1.1	1.1	0.1	0.06	0.02	0.2	5.5	0.06	4.9	0.6	-
Bear Creek at Ramsey, VA	35	99																
Observed			7.2	169.0	-	-	-	7.3	7.5	0.8	-	0.62	1.1	-	-	24.0	14.0	-
Simulated			6.8	5.2	-	-	-	1.1	1.1	0.1	-	0.02	0.2	-	-	5.0	0.6	-
Gap Creek near Arthur, TN	21	62																
Observed			7.2	13.7	0.6	0.08	224	3.2	3.0	0.07	0.02	0.03	0.2	10.0	0.05	39.0	4.3	1.7
Simulated			7.8	5.2	0.6	0.04	146	2.0	1.2	0.1	0.06	0.02	0.2	4.9	0.06	40.0	8.0	1.7

adequate for simulating background conditions to be compared with after-mining values. Observed sulfate values for Bear Creek considerably exceed the simulated values, indicating that even this presumed background watershed may have been mined. Improvement in the accuracy of simulated values for coal-associated constituents would require more data, and probably some field data. As this model can now be applied with only mapped data, no improvements to this background model are planned.

Development of a Suspended Sediment Model

A suspended sediment model, which is coupled with the project's storm hydrograph component of the streamflow model, has been developed with the use of data from several other studies. Testing of the sediment model developed by Betson (1976) on the two Beaver Creek watersheds (previously described) was not satisfactory. This multiple regression model was not intended for use in this type of study, nor were the results obtained by regenerating the calibration data particularly encouraging. Attention, therefore, has focused on the Universal Soil Loss Equation (USLE) and adaptations of it for several reasons: (1) A considerable body of research and experience is associated with it, (2) it includes the principal factors affecting erosion, and (3) it is consistent with other components of the model in that it is simple and easily applied.

As originally developed by Wischmeier and Smith (1965), the USLE was used to estimate annual soil loss from agricultural lands on the basis of rainfall energy, cover, and physical characteristics. The equation was adapted by Williams (1975) to substitute the product of the storm runoff volume times the peak discharge for the rainfall energy term in the original equation, thus allowing for sediment to be determined for individual storms. This adaptation makes the USLE attractive for this project because (1) it can be interfaced with the hydrological models, (2) it contains factors important in describing sediment generation from mined areas, and (3) research is going on elsewhere to adapt the technique to mining and construction sites. A test of the modified USLE was, therefore, undertaken with the use of data from the Upper Bear Creek experimental project located in northwest Alabama (TVA 1973). For this test, a linear relationship between observed storm sediment loads and the product term (storm runoff X peak discharge) was determined by using several storms at each of six of the smaller watersheds in the project. The modified USLE was then solved backward for the land cover term "C." This latter term was then estimated directly from land cover by using suggested values obtained from McElroy et al. (1975); Table 13 summarizes the results.

TABLE 13. TESTS OF UNIVERSAL SOIL LOSS EQUATION--
UPPER BEAR CREEK WATERSHED DATA

Sub-watershed	Area (km^2)	Land cover factor "C"		Percent forest
		From data	Based on cover	
SF1	6.42	0.011	0.002	100
SF2	36.0	0.002	0.016	85
SA1	5.18	0.152	0.164	22
SA2	18.6	0.052	0.098	42
SC1	2.25	0.187	0.135	25
SC2	4.97	0.140	0.129	29

Results of this test indicated that the modified USLE is capable of accounting for a range of storm conditions and that the terms in the equation can be estimated reasonably on a watershed scale. Williams (no date) proposed further modification of the USLE which would permit distribution of the storm sediment load across the storm hydrograph. For this technique, an instantaneous unit sedograph (IUSG) is developed on the basis of a relationship among the peak discharge, the maximum value of source area runoff, and the time to peak. All these values are available in the storm hydrograph model in such a manner that this sediment distribution algorithm is deterministic because no model parameters are needed to use it. The algorithm was tested by using storm hydrograph and sediment data from the Upper Bear Creek study (TVA 1973) and from an urban hydrology study conducted in Knoxville, Tennessee (Betson 1976). These tests indicated that this technique did allocate the storm sediment reasonably well. The sediment distribution algorithm was also tested by using data from the mined Cane Branch watershed in the Beaver Creek project. Figure 16 shows a simulated storm hydrograph and sediment concentration relationship vs. observed values obtained from Musser et al. (1970). For this storm, suspended sediment totaled 96 tonnes from the 1.74-km^2 watershed.

Development of a Water Temperature Prediction Model

Water temperature information will be needed in several model components, such as the models for routing of suspended sediment and aquatic biota. Obviously, because water temperature data would not have been previously collected for a planning model application, a method for predicting these data must be devised. Water and air temperature data collected at four sites in the Cumberland Plateau physiographic province from Alabama to Kentucky were analyzed with a regression model that used moving average air temperature as the independent variable. An average equation was found to be capable of predicting water temperature:

$$WT = 2.4 + 0.86AT_3,$$

where

WT = water temperature, °C,

AT_3 = 3-day average air temperature, °C.

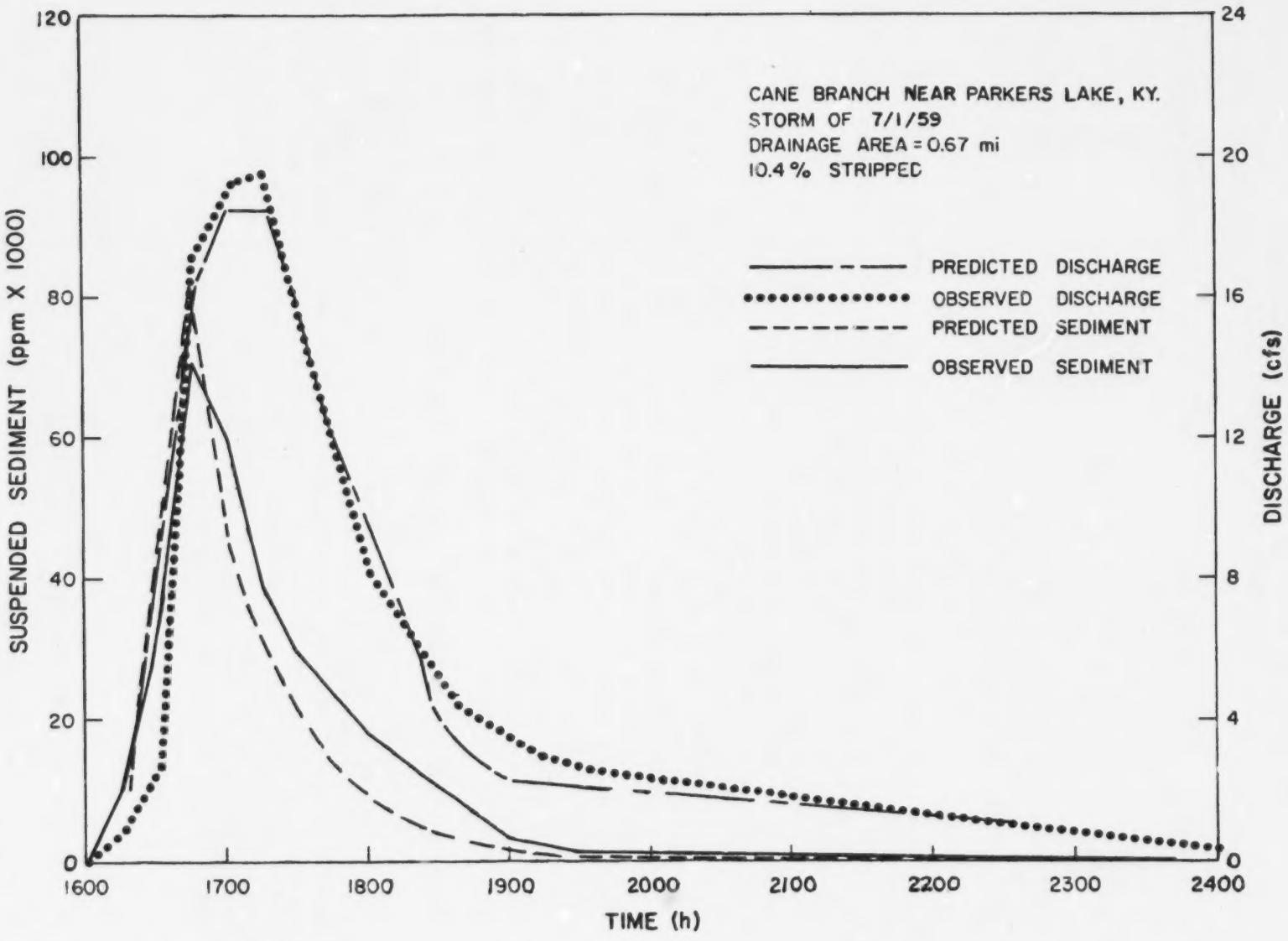

Figure 16. Results of TVA suspended sediment-storm hydrograph model.

The relationship is a "hockey stick" function because, when $AT_3 < 0°C$, $WT = 0°C$. Figure 17 shows a year of observed and predicted water temperatures for Carr Fork near Sassafras, Kentucky. The relationship shown in the figure explained 92 percent of the variance. For applications involving stochastic, long-term simulations, water temperatures will be approximated with a sinusoidal function.

Development of a Channel Geomorphology Model

Routing streamflow and water quality constituents downstream from first-order streams to locations at which a viable aquatic ecosystem might be impacted requires a model that will use channel measures. Channel dimensions are particularly difficult and expensive to measure in coal-mining areas because of the rugged terrain and dense vegetation. Therefore, a channel morphology model was developed so that these channel measures can be predicted with the use of readily available information.

In developing this model, stream discharge measurement data from some 50 stream gage sites located in the Cumberland Plateau province were obtained from Kentucky offices of the USGS. These stations were thought to be virtually unaffected by mining in their watershed, and for those stations located at a bridge, the cross section was not thought to be significantly affected by the bridge. Further screening reduced the number of stations used to 34. Relationships between instantaneous discharge and channel width and area were then developed by regression. The basic equations are

$$W = aQ^b$$

and

$$A = cQ^d,$$

where

W = channel width, m,

Q = stream discharge, m^3/s,

A = channel cross-sectional area, m^2,

a,b,c,d = coefficients.

From these two equations, two other channel measures can be derived:

$$HD = A/W$$

and

$$V = a/cQ^{(1-d)},$$

where

HD = hydraulic depth, m,

V = velocity, m/s,

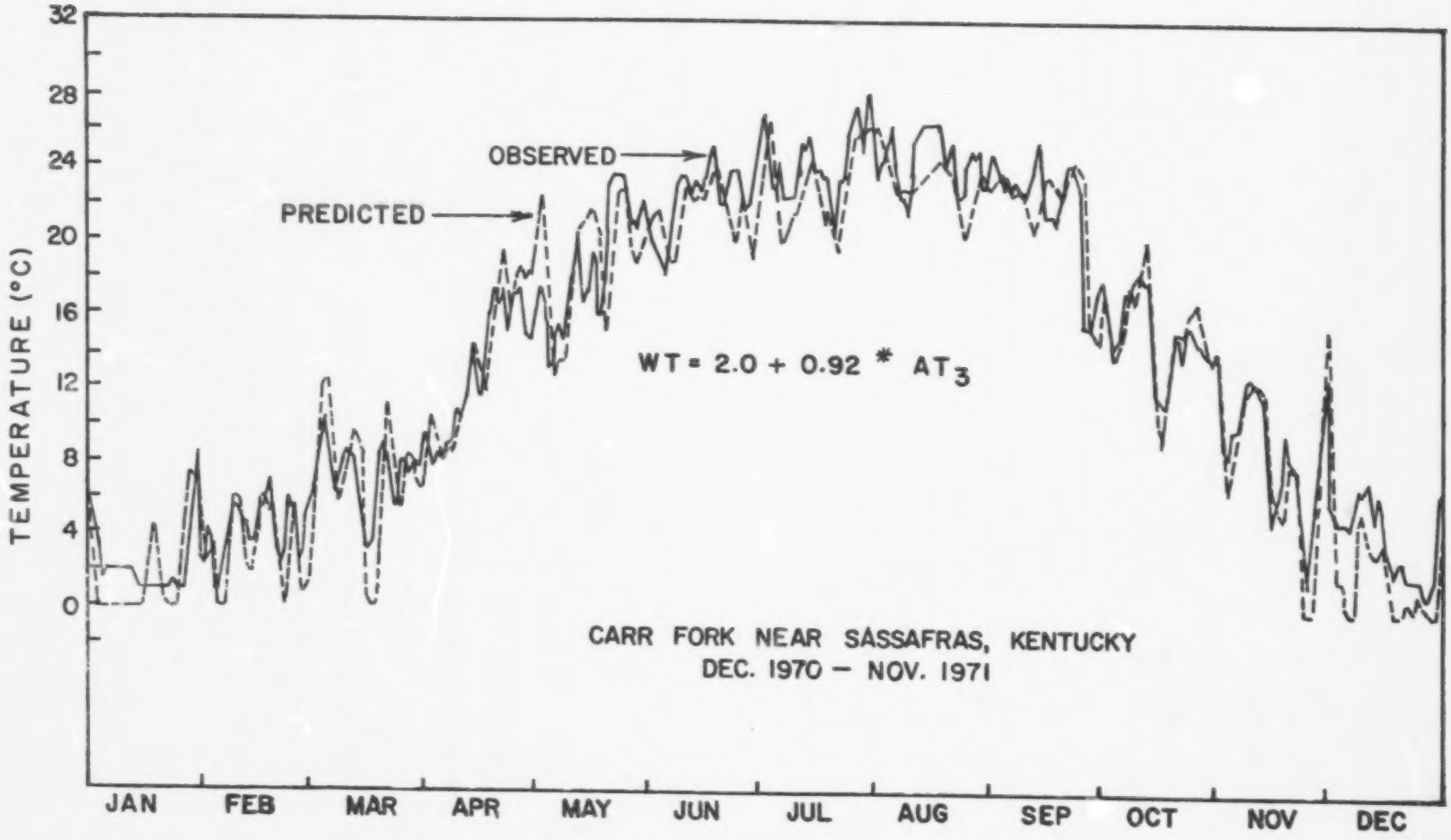

Figure 17. Comparison of observed and predicted stream temperatures.

The four coefficients in the equations were next used as dependent variables in regression equations using, as independent variables, the channel slope (SL) near the gage sites, measured from a topographic map, and the drainage area (DA). The resulting equations are

$$a = 0.453\ DA^{0.545}\ SL^{0.565},$$

$$b = 1.134\ DA^{-0.239}\ SL^{-0.294},$$

$$c = 0.038\ DA^{0.611}\ SL^{0.772},$$

$$d = 1.507\ DA^{-0.0987}\ SL^{-0.166}.$$

The model was tested at several gage sites not included in the calibration data set. Preliminary results indicate that the model is adequate for routing purposes and, in some cases, provides a better measure of general channel morphology than actual data at some stream gages (which were not located with this purpose in mind). Figure 18 shows the results obtained at a test watershed.

Extension of the Storm Hydrograph Model Regionalized Relationship

As explained in the description of tests using data from the Beaver Creek, Kentucky, watershed, the results obtained when storm hydrographs at the two watersheds were simulated indicated that the regionalized relationships were not adequate. Since the model had not previously been calibrated in this physiographic province, this finding was not too surprising. Therefore, storm hydrograph and rainfall data were obtained for five stream gages located in this province from the USGS, Nashville District. Because these streams drain unmined watersheds, the data will be used to improve the regionalized relationships used to predict background storm hydrographs. Information on the stations, by Wibben and Boyd (1975), is summarized in Table 14.

TABLE 14. BACKGROUND WATERSHEDS FOR MODEL CALIBRATION LOCATED IN CUMBERLAND PLATEAU

Watershed	Drainage area (km^2)	Number of storms analyzed
Bitter Creek near Camp Austin, TN	14.3	18
Raccoon Creek near Old Winesap, TN	3.94	12
Self Creek near Big Lick, TN	9.84	21
Forked Creek near Oakdale, TN	6.32	10
Byrd Creek near Crossville, TN	2.85	19

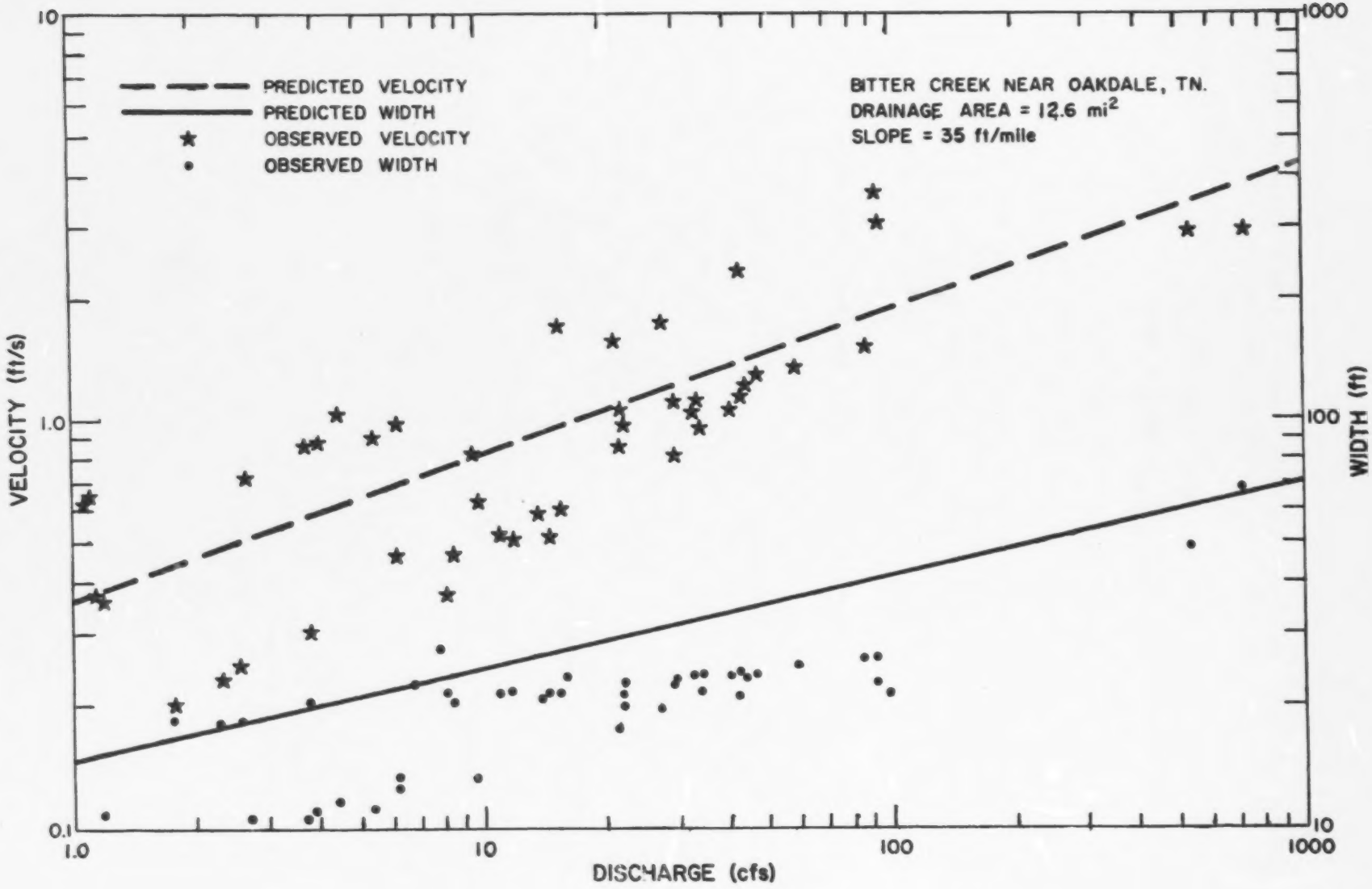

Figure 18. Results of TVA geomorphic model.

The relationships among the model parameters and the watershed characteristics for these five background watersheds and the results obtained from analyzing 21 storms at Helton Branch in the Beaver Creek project and the three project background watersheds (Bowling, Lowe, and Long Branches) will provide ample information for improving the regionalized relationships.

SECTION 6

MODEL COMPONENTS

EXPLANATION OF MODEL COMPONENTS AND LINKAGES

Figure 19 shows the components of the strip mine drainage model. This schematic was developed to show the interrelationships among the components, the principal linkages, and the location of the decision-making nodes.

The top three component blocks in the schematic show the types of basic site information that will be needed to operate the model. These data provide information to the model that allows it to handle the unique characteristics of each site. Much of the information in the left block can be obtained rather easily from maps, published information, and aerial photographs. Time-varying data, such as rainfall, streamflow, or climatic information, will not be required for application of this model, as are most hydrology-driven models of this type. Site data, however, will be required to describe the overburden geochemistry (center block) and the mining and reclamation techniques (right block). The core samples can be obtained during site investigation drilling in those locations for which no previous overburden analyses have been performed, and information on the strip mine characteristics can be obtained from the mine permit applications.

The first-order stream hydrology model is a nonpoint source model that is used to simulate streamflow immediately below mine sites (drainage area, 2 km^2 plus) and from unmined or background areas. This model component, which adjusts for differences in mining technique and handles the effect of sedimentation ponds, drives the rest of the system.

The first-order water quality model, also a nonpoint source component, is used to predict water quality constituent transport from the mined and unmined areas of a watershed in conjunction with the streamflow model. Suspended sediment is a principal constituent of concern in this model. The streamflow model provides, however, for transporting other constituents in various pathways so that any constituent of environmental concern can be handled.

A shortened version of the model, using the first-order streamflow and quality components only, can be used to assess the capability of a proposed mine to meet regulatory criteria as shown in the upper decision node. In other words, the model could be used to simulate the effects of a given mining scenario, but if the simulation would not meet quality criteria, additional protection measures could be tried until the simulations met the criteria.

The quality and quantity simulations from the first-order streamflow model components are next routed downstream on the basis of channel morphology. At a point well downstream at which a viable fishery resource could exist, the routed streamflow quantity and quality are input to the aquatic biota and fisheries resource model components.

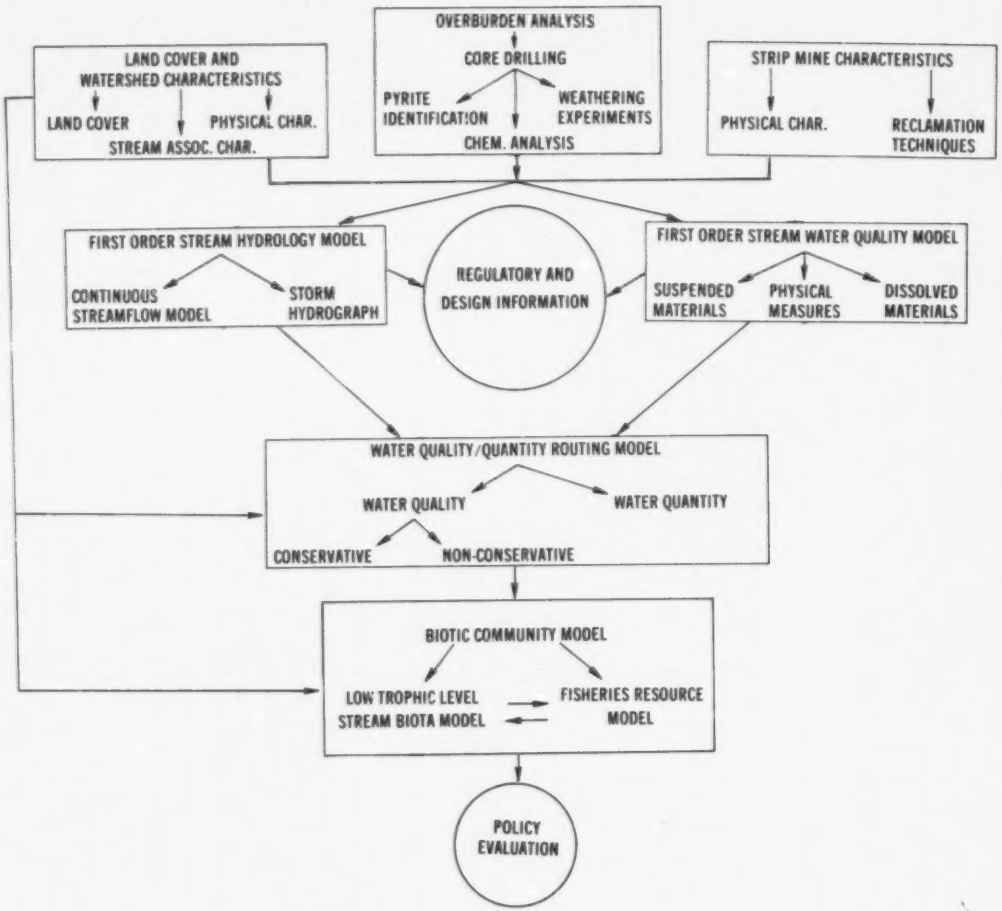

Figure 19. Schematic diagram of model components.

These latter components are important features of this model because they allow the linking of cause and effect, which will permit a decision-making dimension not possible when only water quality criteria are considered.

The policy evaluation node at the bottom of Figure 19 is located there to indicate that, with the entire model in operation, the impact of mining can be assessed in relation to (1) natural or background conditions, (2) changes to the streamflow and water quality regime, and (3) changes to the aquatic biota of the stream. Synergistic effects, such as the burial of benthic habitat coupled with changes in water quality, can be evaluated. Therefore, this linkage will allow evaluation of the tradeoff between the costs of mining and reclamation controls and degradation to the aquatic resource.

PROGRESS ON MODEL COMPONENTS

Overburden Analysis

This phase of the project is patterned after the work of Caruccio et al. (1976), which has shown the importance of framboidal pyrite in determining the acidity of leachate. Overburden core samples were taken in the Fentress County study watersheds and above each of the three major coal seams in the New River Basin. Prepared samples of these cores were sent to the University of South Carolina, where Caruccio and his staff are molding pellets that will, in turn, be used to identify the pyrite forms under a microscope. Laboratory apparatus, based on the approach of Caruccio, was set up in the TVA laboratory to artificially weather the overburden samples to determine leaching rates for various constituents determining water quality.

Watershed and Strip Mine Characteristics--

This is the basic information needed to operate the system models. Most of the information on land cover and watershed characteristics is obtained from existing maps or other sources. A few characteristics are obtained from field measurements for use in studies with project data; however, future applications will not require costly field measures. Site-specific information on the mining technique, mine dimensions, reclamation, erosion control measures, and sediment control measures will be needed. In model applications, this information may be obtained from the mine permit application. In the project watersheds, this latter information is obtained from a map of the New River Basin prepared from LANDSAT data by USGS (Hollyday and Sauer 1976) showing conditions as of April 1973; from annual overflight photographs of these areas taken by TVA; or from field measures. The State of Tennessee does have summaries of mining permit information that are used.

First-Order Stream Hydrology Model--

Recent versions of the two components of the hydrology mode being adapted in this study were described in a TVA report on an urban hydrology study (Betson 1976). The two components are a continuous, daily streamflow model used to budget moisture and a coupled storm hydrograph model.

Both models have been regionalized (to the range of conditions in the Tennessee Valley) so that all parameters can be predicted within the model from readily measured, mapped watershed characteristics.

Tests of the continuous, daily streamflow model, which uses data collected in the Beaver Creek Strip Mine Study (Musser et al. 1970), indicate that the regionalized parameter prediction equations for this component model are adequate. Further testing will be required to determine whether these relationships will remain adequate in areas in which contour-mining is more extensive or in which area-mining methods are used. Some additional testing with off-project data is planned; however, most of this testing will be done with project data when streamflow data for one to two full USGS water years become available.

Tests of the storm hydrograph model, which uses the Beaver Creek project data, did not prove adequate when validation was attempted at the Helton Branch control watershed. As noted earlier, some 100 storm hydrographs from six background watersheds were analyzed with an analytical version of this model, and the results will be used to improve the regionalized relationships. Storm hydrographs from project watersheds in the New River Basin (mined and unmined) have been analyzed with this model at the University of Tennessee as part of various thesis projects. These results will also be incorporated into the regionalization analyses.

A version of the coupled models was adapted for use on a computer time-sharing terminal. Input to this version consists of the basic descriptive watershed characteristics, mean monthly land pan evaporation, and a measure of mean monthly rainfall and its standard deviation. Total input is on ten lines. The model produces all rainfall data stochastically and predicts total rainfall and streamflow for each year and the rainfall, runoff, and peak discharge for each large storm that will occur during the year. In limited validation tests (watersheds not located in coal-mining areas), the model was found to be able to reasonably reproduce the observed annual maximum flood flow frequency relationship (25 years) with the use of regionalized relationships to predict model parameters. Those discrepancies that did occur were attributed to the rainfall generator, which has not been tested much for this type of application. Further testing of this model application is planned for watersheds located in coal-producing areas because a model version comparable to this, in case of application, will be part of the final model package.

First-Order Stream Water Quality Model--

The earlier section on model tests with Beaver Creek project data described tests conducted with the background nonpoint source mineral water quality model. These tests indicated that this background model is probably adequate for simulating premining conditions for watersheds in the Cumberland Plateau. No further development is planned for this model, except to extend the capability to additional constituents, if necessary, for the aquatic biota model.

An earlier section also described the suspended sediment model that has been developed. Algorithms for this sediment model have been incorporated into the storm hydrograph model. Earlier, the first-order streamflow model had a capability for simulating daily sediment by using a power function on the daily flows. Regression equations had been developed to predict the terms in this equation (Betson 1976). Incorporation of the storm sediment algorithm eliminated the need for the daily sediment model, resulting in a program change. Consequently, the daily sediment load algorithm was applied to groundwater flow only to provide a capability for simulating background sediment. Next the groundwater and groundwater (background) sediment were incorporated into the storm hydrograph component. With this change, the hydrograph model can now be used during storm periods to simulate (1) groundwater plus stormwater flows and (2) background plus storm sediment loads. Suspended sediment concentrations thus can be simulated continuously. In limited testing, the concentration distribution was found reasonable. It was found, however, that at most locations storms are not adequately sampled, and as a result, validation of these detail simulations is difficult.

The first-order streamflow model has provisions for simulating any water quality constituents that are associated with leaching by using a power function relationship with the daily groundwater flow or total streamflow. Incorporation of a storm sediment model enables simulation of the transport of various constituents associated with storm runoff by using the concept of potency factors introduced by Donigian and Crawford (1976). A potency factor is simply a ratio between the concentration of suspended sediment and that of another constituent. Donigian and Crawford found that this approach could be used to simulate the transport of BOD and nutrients. Because of the high sedimentation rates associated with strip mines, this approach should work for many constituents. As a first cut at modeling water quality, correlations among the concentrations of various constituents and suspended sediment were developed by using project data collected to date. The results were presented in the earlier section describing project data.

Water Quality-Quantity Routing Model--

A watershed model developed at the University of Illinois (Shane 1973) has been tested as a tentative routing model. This model has provisions for inputting observed (or simulated) hydrographs at selected locations; generating hydrographs at other locations on the basis of drainage area ratios; routing water; routing conservative water quality constituents; and calculating dissolved oxygen concentrations and temperature. The relationships used for the conservative water quality constituents are the same as those used in our background water quality model (log conc = log a + b log Q) (Dyer et al. 1973). Streamflow is routed by using a similar relationship between velocity (V) and flow (Q). The advantage of this approach is that, after the V vs. Q relationships are established, routing can be accomplished without field data. The model was tested by routing a storm hydrograph through two gaging stations in Upper Bear Creek, Alabama (TVA 1973). Velocity vs. discharge relationships had been developed earlier for these watersheds by Ardis (1974). The routing tests indicated that this approach and the model were applicable at the project.

A section in the previous chapter described development of a channel geomorphology model. With the geomorphologic model, the relationship between velocity and discharge can be predicted at any location for use in the routing model from channel slope and drainage area, both of which are obtained from topographic maps. This eliminates the need for costly field measurements of channel cross sections.

An equation for predicting sediment concentrations using the "unit stream power" concept was presented by Yang and Stall (1976). The equation uses data on velocity, depth, slope, temperature, and mean bed material diameter, all of which are easily obtained. Several tests of this equation were made by using historic storm data from two Upper Bear Creek project watersheds (one with low sediment loads and one with high loads). Results obtained for several occasions for which high discharge measurements were made (so that velocity and depth were known) were excellent, considering that the mean bed sediment grain diameter had to be estimated. This equation could be used in a sediment routing model; however, it would have to be coupled with algorithms to handle deposition and scouring distributions and the effect of armoring. The suitability of several sediment routing models, including those developed by the USGS (Bennett 1974), Oak Ridge National Laboratory (Fields 1976), and the Corps of Engineers (Thomas 1975), is also being investigated. These latter models are all steady-state models; they also require detailed information on cross section, and in some cases, they require that the model be calibrated to obtain values for some parameters. Obviously, such data requirements are difficult to justify for a planning model.

A field survey of a 1.3-km reach of Crooked Creek, between the mouth of the unnamed mined tributary (site No. 3, Figure 1) and the gage at site No. 4, was conducted in mid-1977. Data on the channel cross section were obtained for use in validating various aspects of the routing model in a strip mine environment. The geomorphic model was found to be able to predict channel dimensions about as well as they could be determined in the field. (Because the measures are related to discharge, this had to be estimated by using Manning's equation.) The model could not, of course, account for localized conditions caused by obstructions in the channel or the consequences of localized aggregation in the channel below mined tributaries. Tests of the Yang equation for predicting sediment concentrations at measured cross sections with the use of field-measured slopes indicated differences among the sections related to the condition of the channel (i.e., the carrying capacity would be low in reaches in which sediment was deposited). These data will be used in hydrograph routing tests as soon as sufficient data on suspended sediment are collected from the project watersheds to allow determination of realistic sediment concentrations and flows from the source areas.

Biotic Community Model--

Artificial channels were constructed and modified on the basis of preliminary tests with aquatic biota taken from project streams in the Fentress County area. These artificial channels will be used to quantify the effect of expected changes in water quality resulting from mining on productivity of indigenous biota. Toxic or subacute effects resulting from increased levels of trace metals will also be studied.

The aquatic biota model will consist of two components, one module for low-trophic-level biota and one for fisheries. Figures 20 and 21 show the generalized flow charts for these components. The fluxes among modules are shown, and output from the benthic module is input to the fish module. Rather than identify individual species within the model, functional groupings will be used. The model will be expressed as a series of differential equations that, when integrated, will provide the change within the compartment over time. The final model will be able to address either numbers or biomass. Impacts resulting from mining that may disturb the system can include temperature changes, toxic substances (trace metals), catastrophic discharges (floods, spates), and sedimentation. Conceptual functional relationships expressing the effect of these disturbances on the biotic system have been developed.

The transfer coefficients necessary to quantify fluxes among the module components are being obtained from the field data collected at watersheds in the Fentress County project (described earlier in this report). Although these data will be somewhat site-specific as a result of using functional biotic groupings rather than species, generalizations can be made, and the model can be applied elsewhere by using data published in the literature.

Decision Nodes--

Because the purpose in developing this model is to provide planners with a tool for use in decision making (as opposed to developing a model to study the effects of mining), the needs of two types of decision makers were considered. Figure 19 shows a decision node termed "Regulatory and Design Information" and another termed "Policy Evaluation." These two decision nodes reflect the needs for two quite different levels of decision makers who could use this model.

When water quality criteria are provided as a constraint, components of the first-order stream hydrology and water quality models can be used to simulate the effect of a proposed mining, reclamation, and sedimentation control methodology to determine whether regulatory constraints will be met. In effect, this shortened version of the model can be used to evaluate and, if necessary, improve the design.

Rigid water quality criteria, however, are not always applicable in a given situation. The criteria may be more restrictive than background conditions, or they may impose costly constraints that result in no tangible benefits to the aquatic ecosystem. Mining impacts the aquatic system only when it affects living organisms. Therefore, there is a second decision node that uses the entire model. At this node, policy decisions can be made to evaluate (1) the effect of allowing variances to water quality criteria, (2) the applicability of the criteria, or (3) the accumulative effect of extensive mining within a larger watershed.

Figure 22 was developed to depict the appearance of this model from the point of view of either decision maker. As shown, general basic information describing the site to be mined will be required. The user will not be concerned with model coefficients or parameters--the sorts

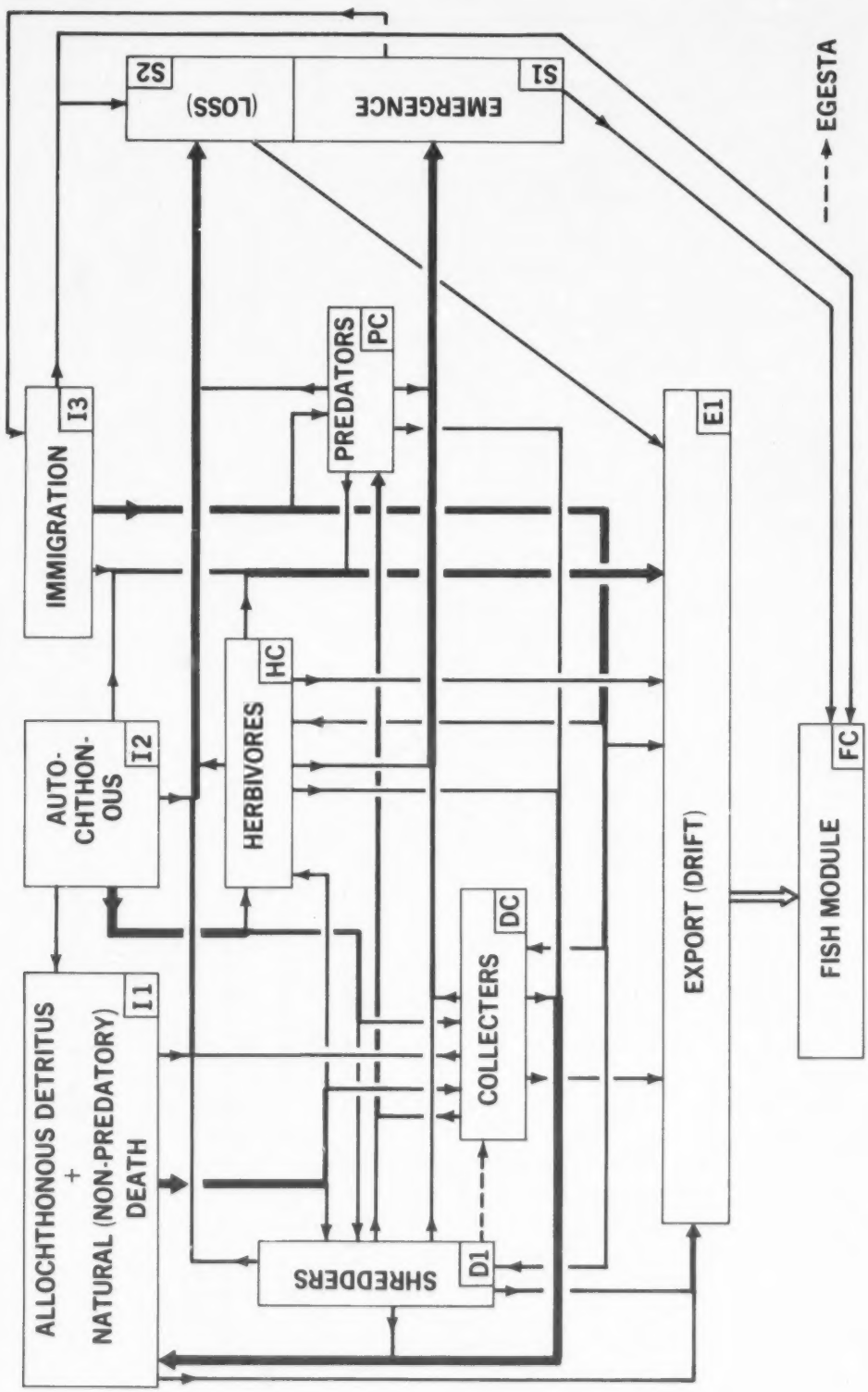

Figure 20. Generalized benthic module: Biological model, Jamestown area streams.

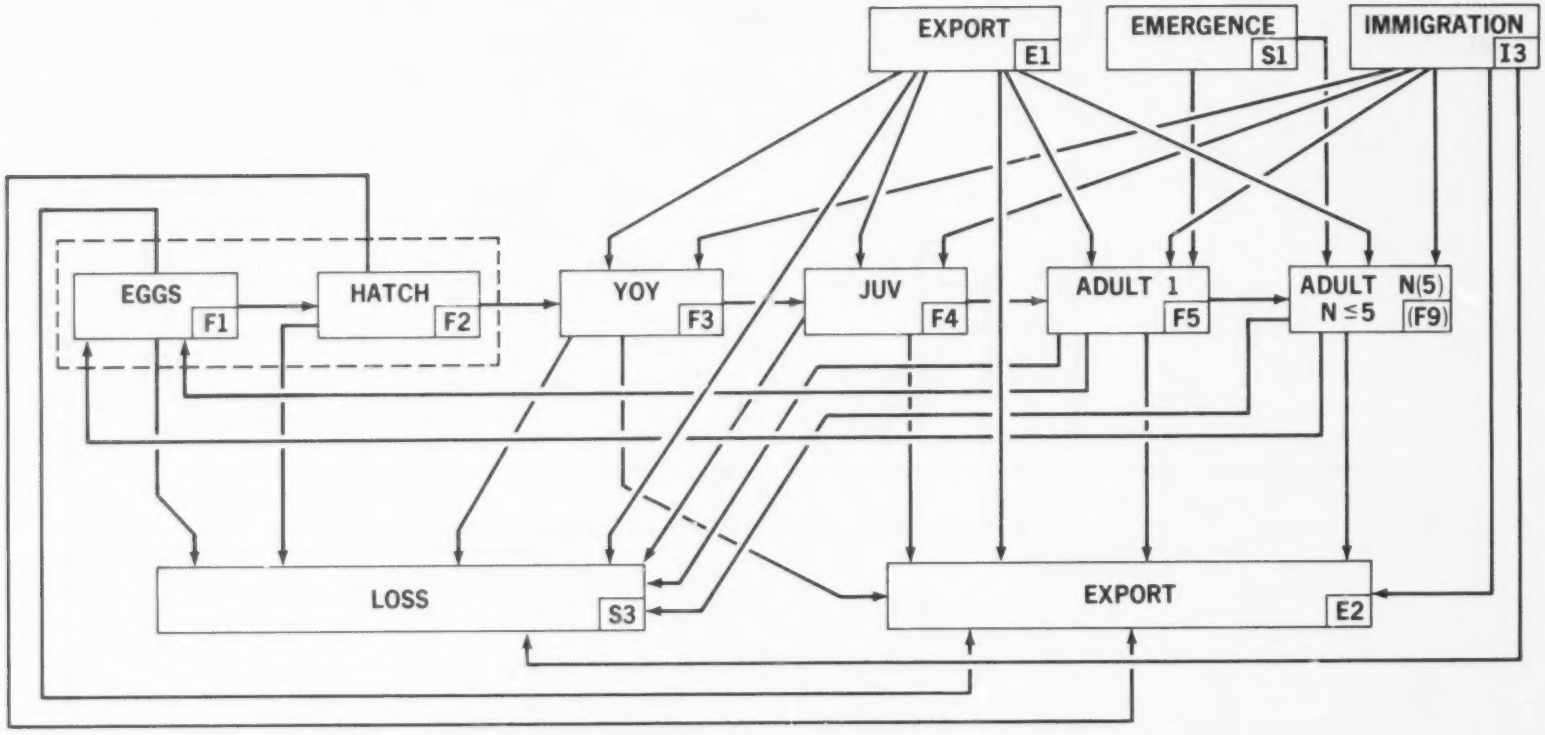

Figure 21. Fish module: Biological model, Jamestown area streams.

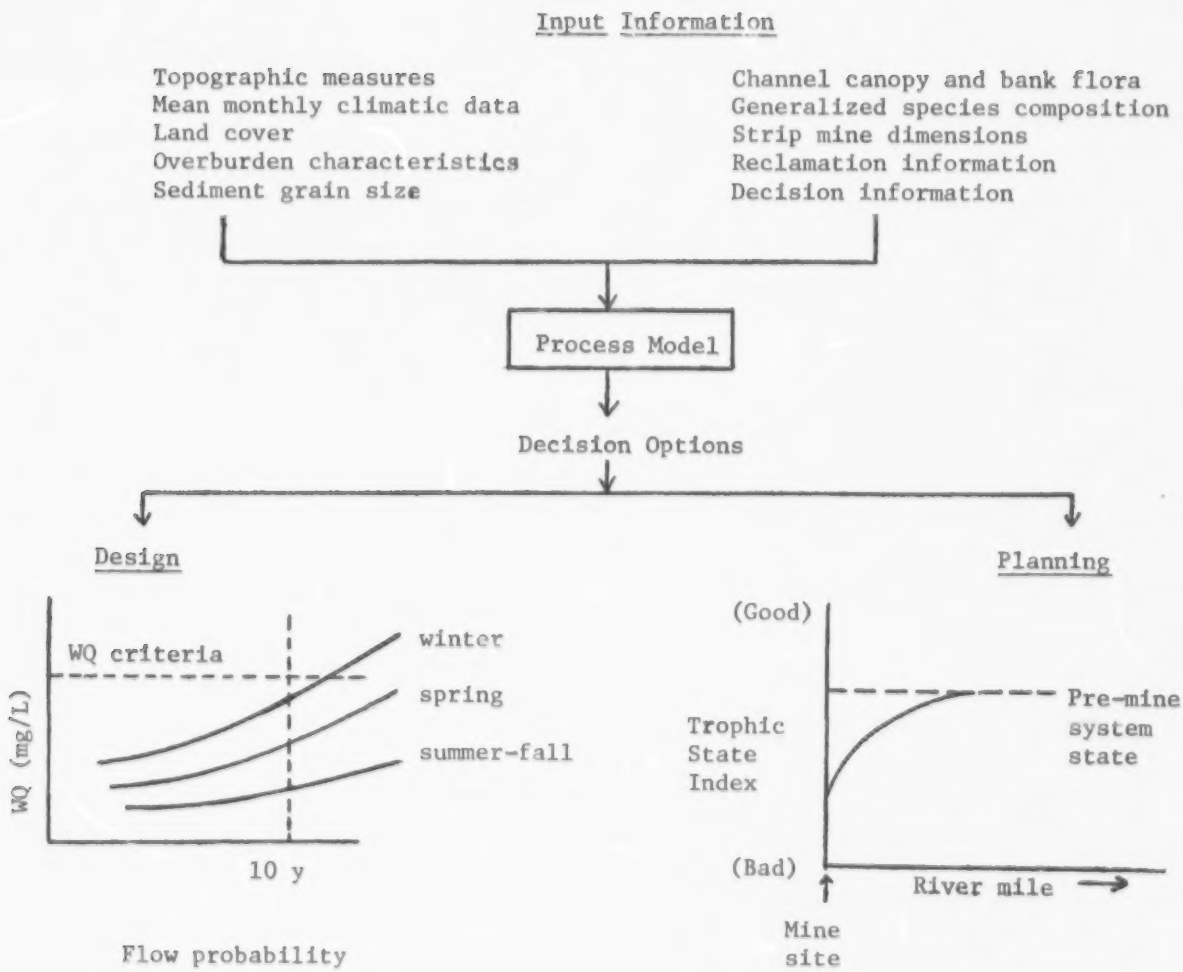

Figure 22. TVA strip mine impact assessment model.

of numbers that must be estimated by professionals or modelers. Output from the system will be specific to his needs and will show, for example, in the design node whether the proposed configuration will meet appropriate water quality criteria. If the entire model is used, the output might depict the degree and extent to which a downstream river could be impacted.

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APPENDIX A

STATE OF TENNESSEE STRIP MINE REGULATIONS

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STATE OF TENNESSEE STRIP MINE REGULATIONS

Law	Regulation--major impacts and changes
No law prior to September 1967.	No State strip mine control prior to September 1967.
September 1967--Tennessee Strip Mine Law of 1967. First State provision for strip mine regulation and control, permits reclamation, enforcement.	September 1967, Regulations Pertaining to Surface Mining; General regulation of complete backfill cover against lightwall; placement and grading of spoil banks and overburden to favor revegetation; drainage ditches; erosion and sediment control structures; revegetation program; broad time-period constraints; $400/acre bond required.
March 1972--The Tennessee Surface Mining Law, Amendments to 1967 Law.	March 1973, Regulations Pertaining to Surface Mining; More specific regulation criteria; water quality discharge permit application required; major mining constraint on >28° slopes; drainage ditch and culvert criteria; toxic materials segregation; maximum solids, bench width/slope below coal, outcrop criteria; 35° maximum spoilbank slope; 30-foot maximum highwall exposure; 10-foot minimum fill above coal seam; grasses and trees revegetation required; general limitation on head-of-hollow mining; $600/acre bond requirement.
March 1974--The Tennessee Surface Mining Law, Amendments to provide for more specific regulation and control to minimize injurious environmental surface mining effects.	June 1974, Regulations Pertaining to Surface Mining; More specific regulation criteria and rules; newspaper notice of permit application required; water quality discharge permit required prior to mining application; prospecting permit required; specific rules on access roads plans; 28° slope limitation on mining; 125-foot downslope spoil limit below cropline for slopes <28°; 20-foot maximum highwall exposure before July 1, 1975--no highwall after July 1, 1975, on new cuts; landslide prevention rules; no mining within 25 feet of wet-weather drainage centerlines; no mining within 100 feet of flowing stream centerlines; $1,000/acre bond requirement.

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STATE OF TENNESSEE STRIP MINE REGULATIONS (Continued)

Law	Regulation--major impacts and changes
	December 1975, Addendum to Regulations Pertaining to Surface Mining; Adoption of drainage control handbook for controlling mine haul road water runoff and sediment; major revegetation changes, including agricultural lime rates, mulch requirements, and seeding rates.
	July 1976, (Proposed) Addendum to Regulations Pertaining to Surface Mining; 50-foot downslope spoil limit for slopes <28°; brush clearance area disturbance and barrier below spoil--not to exceed 125-foot downslope from cropline; 30° maximum spoilbank slope; 100-foot distance limitation.

APPENDIX B

ZOOMACROBENTHOS COLLECTED IN THE VICINITY OF JAMESTOWN, TENNESSEE

Annelida
  Oligochaeta

Crustacea
  Cambarus sp.
  Hyallela azteca
  Immature decapod

Coleoptera
  Hydrobius sp.
  Ectoparia sp.
  Gonielmis dietrichi
  Helichus sp.
  Optioservus immunis
  Promoresia elegans
  Oulimnius latisculus
  Derovatellus sp.
  Phycoetes sp.
  Pelonomus obscurus

Collembola
  Isotoma sp.
  Smynthurus sp.

Diptera
  Pilaria sp.
  Antocha sp.
  Unknown Chironomidae
  Dicranota sp.
  Dixa sp.
  Dolichopodidae
  Hemerodromia sp.
  Hexatoma sp.
  Limonia sp.
  Limnophila sp.
  Ormosia sp.
  Palpomyia sp.
  Paradelphomvia or Pseudolimnophilia sp.
  Tipula sp.
  Simulium sp.
  Tabanidae
  Tabanus sp.
  Crysops sp.
  Heleidae pupa
  Bezzia or Probezzia sp.

Hemiptera
  Gerris sp.
  Microvelia sp.
  Rhagovelia sp.

Ephemeroptera
  Ameletus sp.
  Baetis sp.
  Ephemera sp.
  Ephemerella sp.
  E. excrucians
  E. lutulenta
  E. simplex
  Hexagenia sp.
  Leptophlebiidae
  Stenonema sp.
  Habrophlebia sp.
  Habrophleboides sp.

Lepidoptera
  Nymphula sp.

Megaloptera
  Corydalus cornutus
  Nigronia sp.
  Sialis sp.

Pelecypoda
  Psidium sp.
  Sphaerium sp.

Odonata
  Calopteryx (syn. Agrion) sp.
  Boyeria sp.
  Cordulegaster sp.
  Gomphus (Gomphurus) sp.
  Hetaerina sp.
  Dromogomphus sp.

Plecoptera
  Acroneuria sp.
  Diploperla, Isoperla sp.
  Hastaperla sp.

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APPENDIX C

CORE LOGS FOR STRATA SAMPLES FROM PROJECT WATERSHEDS

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TABLE C-1. LOG OF CORE, JA1

Depth (ft) From	Depth (ft) To	Description[a]	Sample number
0.0	8.2	Overburden	--
8.2	9.5	White to yellow-tan, weathered, friable sandstone, micaceous	JA1-2
9.5	14.0	Creamy white, slightly weathered sandstone	JA1-2
14.0	14.1	Dark-red hematite oxidized iron, Fe_2O_3 sandstone	--
14.1	23.8	Creamy white to yellow, slightly weathered sandstone, 2.1 ft recovered in 9.7 ft, assuming core loss similar to recovered material	JA1-1
23.8	27.5	Dense gray to tan sandstone	JA1-1
27.5	30.0	Coal	JA1-3
30.0	34.2	Light to medium gray claystone with approximately horizontal stratification, carbonaceous inclusions	JA1-4

[a]All sandstones are slightly micaceous and show essentially horizontal stratification. Strata B, C (JA1-2) and E and F (JA1-1) are all similar sandstones, but show progressively less weathering with depth. This might be reflected in chemical analysis.

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TABLE C-2. LOG OF CORE, JA2

Depth (ft) From	Depth (ft) To	Description[a]	Sample number
0	7	Overburden	--
7.0	21.4	Cream to tan sandstone, crossbedded in part (very poor recovery = 1.5 ft in 14.4 ft); this indicates most of internal was highly weathered and friable sandstones	JA2-3
21.4	23.0	Yellow to tan siltstone, yellow-like hydrous oxides of iron	JA2-4
23.0	36.4	Tan, moderately weathered sandstone	JA2-2
36.4	41.0	Grayish tan, slightly weathered sandstone	JA2-2
41.0	43.8	Yellow tan, highly weathered, friable sandstone	JA2-3
43.8	52.4	Grayish tan, slightly weathered sandstone	JA2-2
52.4	53.0	Gray sandstone with thin carbonaceous strata	JA2-5
53.0	55.3	Coal	JA2-1
55.3	56.5	Dark gray carbonaceous shale	JA2-6
56.5	58.5	Gray stratified shale with carbonaceous inclusions	JA2-5

[a]Strata B, D, E, F, and G are all sandstones, but reflect varying degrees of weathering.

TABLE C-3. LOG OF CORE, JA3

Depth (ft) From	To	Description	Sample number
15	16	Bag sample	JA3-1
18	19	Bag sample	JA3-2
21	22	Bag sample	JA3-3
24	25	Bag sample	JA3-4
30	31	Bag sample	JA3-5
33	34	Bag sample	JA3-6
27	28	Bag sample	JA3-7
9	10	Bag sample	JA3-8
12	13	Bag sample	JA3-9
6	7	Bag sample	JA3-10
3	4	Bag sample	JA3-11
0	3	Bag sample	JA3-12

TABLE C-4. LOG OF CORE, G1

Depth (ft) From	Depth (ft) To	Description[a]	Sample number
0.0	6.4	Overburden	--
6.4	6.6	Alternating thin strata of clay and sandstone (overburden)	--
6.6	6.7	Yellow tan, slightly weathered sandstone	G1-1
6.7	11.5	(Core loss - assume similar to recovered material 11.5 - 12.0)	G1-1
11.5	12.0	Yellow tan, slightly weathered sandstone	G1-1
12.0	15.6	Light gray, dense sandstone	G1-1
15.6	17.3	Medium gray claystone	G1-2
17.3	18.9	Light gray sandstone	G1-1
18.9	20.0	Coal (G1-3)	G1-3
20.0	20.5	Light gray claystone with considerable black carbonaceous inclusions, fossil stems	G1-2
20.5	23.9	Light gray siltstone with small amount of carbonaceous inclusions	G1-4

[a]Strata C, D, and F are all sandstones, but reflect varying degree of weathering.

TABLE C-5. LOG OF CORE, NR1

Depth (ft) From	To	Description	Sample number
0.0	8.3	Overburden	--
8.3	17.7	Highly weathered siltstone interbedded with clay soils; horizontally stratified	B1
17.7	21.6	Relatively dense, unweathered siltstone	B2
21.6	34.5	Slightly weathered siltstone	B3
34.5	42.8	Dense sandstone with thin, essentially horizontal, carbonaceous strata	C1
42.8	78.0	Shale with thin, horizontal, carboniferous partings	D1
78.0	94.4	Carboniferous shale	D2
94.4	94.7	Coal (see E2)	E1
94.7	110.5	Carboniferous shale (see D_2 above)	D2
110.5	124.0	Slightly carboniferous shale	D3
124.0	125.0	Coal	E2
125.0	135.0	No recovery	--
135.0	136.1	Siltstone with carbonaceous partings; insufficient for sample; similar to stratum D_1 above	D1
	136.1	Bottom of boring	--

TABLE C-6. LOG OF CORE, NR2

Depth (ft) From	Depth (ft) To	Description	Sample number
0	277.5	Overburden to top of rock	--
277.5	284.0	Medium gray, calcareous shale interbedded with thin bands of calcareous siltstone	NR3-1
284.0	285.5	Light to medium gray, fine, micaceous sandstone, slightly calcareous; several very thin shale scams interbedded.	NR3-2
285.5	286.0	Medium to dark gray shale	--
286.0	286.4	Intermingled (mottled), dark gray shale and medium to light gray silt and fine sandstone	--
286.4	288.0	Light to medium gray, micaceous, fine sandstone	NR3-2
288.0	294.9	Medium to dark gray, slightly calcareous shale with band of light gray, fine sandstone interbedded	NR3-3
294.9	297.0	Dark gray, homogeneous siltstone	--
297.0	300.6	Medium to dark gray, silty shale with thin interbeds of light to medium gray fine sandstone	--
300.6	317.0	Dark gray, homogeneous, noncalcareous silty shale	NR3-1
317.0	338.8	Dark gray, noncalcareous shale with seams of black fissile oil shale, varying in thickness from a few inches to 3.5 ft	NR3-4
338.8	342.4	Dark gray shale, mottled with carbonaceous (coal-like) inclusions	--
342.4	372.0±	Interbedded medium to dark gray shale, silt, and fine sandstone, with one oil shale bed from 367 to 369 ft	NR3-3
372.0±	B.H.	Coal	--

TABLE C-7. LOG OF CORE, NR3

Depth (ft) From	Depth (ft) To	Description	Sample number
Top Rock	23.0±	Overburden	--
23.0	31.0	Medium gray, fine sandstone with thin beds of siltstone and shale interbedded	NR2-1
31.0	32.4	Reddish brown, weathered siltstone	--
32.4	33.5	Tan sandstone, porous	NR2-2
33.5	34.4	Filled-cavity, clayey silt from weathered shale and siltstone	--
34.4	35.0	Grayish maroon, firm sandstone	--
35.0	36.4	Filled-cavity, maroon, silty sand	--
36.4	59.0±	Tan to light brown, medium to coarse, porous, friable sandstone	NR2-2
59.0	60.0±	Filled-cavity, weathered sandstone, clayed, sandy silt	--
60.0	63.5±	Dark gray, highly decomposed, shaley siltstone	NR2-3
63.5	65.7	Tannish gray, fine sandstone	NR2-4
65.7	75.6	Dark gray, fissile, oil shale, thin-bedded and highly decomposed	NR2-3
75.6	78.9	Medium gray, fine sandstone, interbedded with thin bands of gray siltstone	NR2-4
78.9	82.5±	Dark gray, highly decomposed, silty shale	NR2-3
82.5	85.2	Tannish gray, fine sandstone	NR2-4
85.2	89.0	Dark to medium gray, interbedded shale and siltstone, highly decomposed	NR2-3
89.0	92.0±	Light to medium gray, interbedded shale, siltstone and fine sandstone	NR2-4
92.0±	B.H.	Coal	--